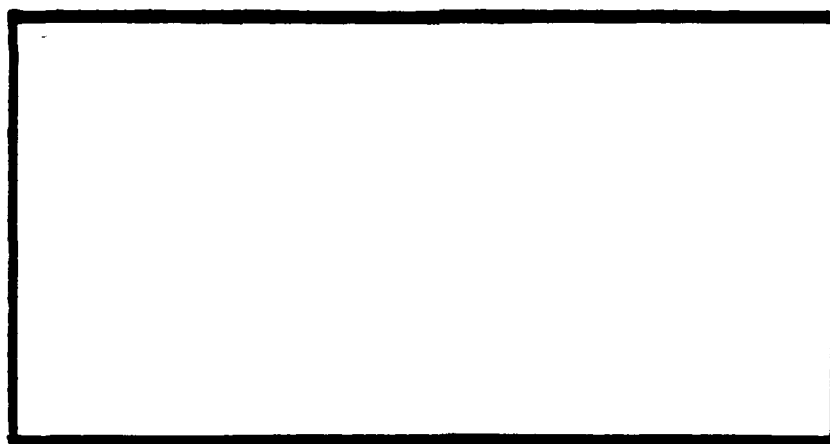


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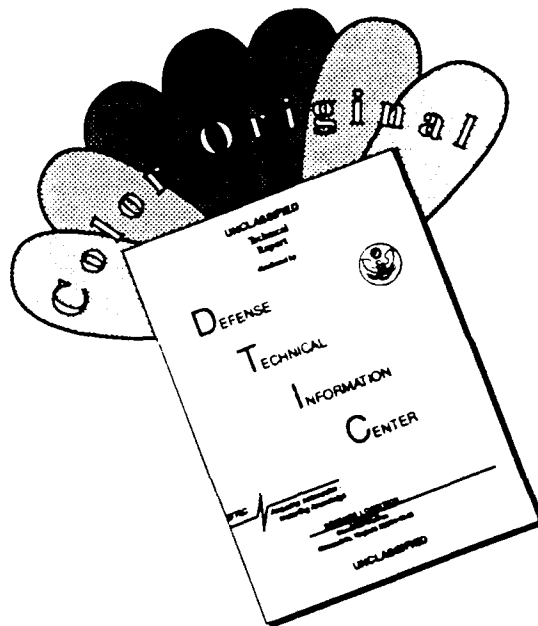
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AN ENVIRONMENTALLY CONTROLLED CHAMBER
FOR THE STUDY
OF RADON DETECTION

THESIS

William R. Wharton, Jr, Capt, USAF

AFIT/EN/GNE/91M-11

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AN ENVIRONMENTALLY CONTROLLED CHAMBER
FOR THE STUDY OF RADON DETECTION

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Nuclear Engineering

William R. Wharton, Jr., B.S.

Captain, USAF

March 1991

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Preface

The purpose of this thesis was to develop an environmentally controlled chamber to aid in the study of radon. The goal was to monitor and control the concentration of radon and the temperature in the chamber. Relative humidity and barometric pressure were also to be monitored and recorded. To accomplish these objectives, several devices had to be designed and fabricated because these specialized pieces of equipment were not available on the market.

I received a great deal of help and support during this project. I wish to express my gratitude to my faculty advisor, Dr. George John, for his assistance, patience, and guidance throughout this work. I especially appreciate the freedom which he allowed me in developing my own ideas, and pursuing them to fruition.

The ultimate success or failure of this project hinged on successfully developing a device which could precisely measure radon and inject it into the environmentally-controlled chamber. Also of importance was the fabrication of a temperature stabilized environment for the Lucas cell alpha detector which was used. My heartfelt thanks are extended to the personnel of the AFIT Fabrication Shop for their genuine interest and dedicated efforts in fabricating the necessary hardware which

made this project a success. Finally, I want to thank my daughter, Cindy, for letting me have the time to finish this work, and especially my wife, Charlotte, for her constant encouragement, love, and understanding.

William R. Wharton, Jr.

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Abstract

A system was developed to dynamically control and monitor the environment and radon concentration within a glovebox chamber for the study of radon. The system is designed around a personal computer workstation which automates the entire system. The radon concentration is determined by monitoring the count rate from radon and its progeny which are continuously circulated from the radon chamber through a Lucas Cell detection system. This information is then used as a base for controlling a radon injection system. When the concentration within the glovebox drops, the system injects a precisely-measured volume of high activity radon gas into the glovebox to return the concentration within the chamber to its normal equilibrium concentration level. The temperature of the chamber is controlled by the use of a temperature-controlled bath, which circulates its fluid through a radiator inside the chamber. Relative humidity and atmospheric pressure within the chamber are not controlled, but are, however, monitored continuously and recorded along with the radon concentration and temperature data. The system, while operating autonomously, has features built into the software that allow the operator to manually control the operation of the radon injection system. The system was successfully fabricated, integrated, and tested. The system maintains the radon concentration within the glovebox

at approximately 120 picocuries per liter. The temperature control system does not maintain a constant temperature within the chamber due mainly to inadequate capacity on the part of the heating/cooling unit which was used. This limits the utility of the temperature control system when temperatures in the laboratory are extreme.

AN ENVIRONMENTALLY-CONTROLLED CHAMBER
FOR THE STUDY
OF RADON DETECTION

I. Introduction

This thesis describes the design, assembly, and testing of a chamber for use in the study of radon. The completed system provides dynamic control over radon concentration and temperature while also monitoring the relative humidity and the atmospheric pressure in the chamber. A Zenith Z248 personal computer, central to the system, performs all necessary data processing and provides control outputs to peripheral equipment. The system functions on an around-the-clock basis as a stand-alone control center for the chamber. The computer software also enables the user to interactively exercise manual control over the system. On-screen reporting of the data in both numeric and graphic format is provided, as well as a permanent logging feature that records the data on the computer hard disk.

A versatile, integrated system of this type is invaluable in the study of radon detection. By having a chamber in which the radon concentration and temperature are regulated and the atmospheric pressure and relative humidity are monitored, it is possible, for instance, to study the absorption of radon

as a function of these parameters. The study of radon can be made much easier by having a system that automatically performs constant data monitoring and logging and where a number of features are incorporated to allow manual intervention as well.

The chamber used in this study is a sealed glovebox with a volume of approximately 350 liters and 0.1 μCi of a dry ^{226}Ra source in a covered beaker. This chamber had previously been used for various radon studies, but the chamber lacked a number of desirable characteristics such as a constant, controlled radon concentration and temperature, and a monitored relative humidity and barometric pressure. The glovebox has an airlock through which materials such as charcoal cannisters can be passed. However, each time the airlock is used, the amount of radon in the airlock is lost. In addition, the radon concentration decreases markedly when charcoal cannisters are placed in the chamber because of charcoal's absorption property. This varying radon concentration precludes experiments where a constant radon concentration is required. Also, in the past, the temperature in neither the chamber nor the Lucas cell detector was controlled in any way. The operation of the Lucas cell, as was seen during the course of this project, can be somewhat temperature dependent, and the count rate for a constant radon concentration was found to vary slightly with

temperature. These facts, coupled with the absence of any real permanent monitoring system for any parameters at all, established the need for this work.

This radon chamber control system either controls or provides information on four physical parameters: radon concentration, temperature, relative humidity, and barometric pressure. Of these, relative humidity and atmospheric pressure are only monitored and not controlled. A Solomat MPM4000, used in conjunction with a Solomat MPM4013, performs the monitoring function. This system can be used to monitor environmental conditions and provide a digital output to a computer. To provide environmental information to the Solomat system, two probes containing temperature, relative humidity, and barometric pressure sensors were installed in the chamber. The Solomat equipment was interfaced to a personal computer through an RS-232 port to display and store the data.

An autonomous system is used to maintain the temperature in the chamber without using the Z248 computer. A Neslab Industries RTE-100 temperature-controlled bath circulates a water/ethylene glycol mixture through a radiator that is mounted inside the chamber. This same fluid also passes through a copper coil inside an insulated box, housing the Lucas cell, to help control its temperature. This system provides both cooling and heating as needed.

Control of the radon concentration required the fabrication of a specialized system. Experiments subsequently determined that the 0.1- μ Ci source within the chamber provides an equilibrium concentration of about 120 picocuries/liter (pCi/liter) in the chamber environment. The equipment developed for this project helps maintain that concentration. In the event of a drop in radon concentration, this system brings the radon concentration back up to its equilibrium concentration. This is accomplished by using a secondary radon source, a 100- μ Ci ^{226}Ra source, dissolved in 4-normal hydrochloric acid. The much higher activity per unit volume of this radon than that which is within the chamber provides a source of make-up radon which, when injected in small volumes into the chamber, brings the chamber concentration back up to normal. A device was designed and fabricated to inject precise amounts of make-up radon into the chamber. An interface was also designed and fabricated to allow computer-controlled injection. A counting system using a Lucas cell alpha detector provides counting information to the computer, which then determines the radon concentration in the chamber and whether injection of make-up radon into the chamber is necessary. When that need exists, the computer controls the injection of the radon into the chamber.

All peripheral equipment assembled in this project is ultimately interfaced to a Zenith Z248 personal computer. The computer is programmed to provide a user-friendly interface to the system, manage all the incoming data, display and record appropriate data, and send any necessary control signals to the radon injection device when required.

A number of experiments were conducted to provide calibration points for the system such as the relationship between the alpha count rate and the radon concentration in the chamber. Several experiments tested the response of the Lucas cell to changes in the radon concentration to determine what type of control algorithm was required in the software that controlled the radon injector. Chapter 2 of this thesis presents a detailed description of each piece of equipment that makes up the radon chamber system. Chapter 3 explains the experiments performed in the formation of the control theory used to regulate the radon concentration. The control theory that was subsequently developed is presented in chapter 4. The final performance of the system is explained in chapter 5, and chapter 6 presents possible future refinements which may be considered to improve the radon chamber system. Specific information on the system and its use can be found in the appendices.

Appendix A explains how to set up the system hardware. Appendix B describes the personal computer setup. A listing of the computer program that controls the system, the radon control program (RCP), can be found in appendix C, and the program is explained in detail in appendix D. Finally appendix E outlines the procedure to program the Solomat MPM4000, a component of the environmental monitoring system.

II. Equipment Description

Overall System Description

A number of diverse pieces of equipment were brought together to assemble the system described in this thesis. A remote workstation was designed and built to control and/or monitor certain parameters in a glovebox located in the radiochemistry laboratory at the Air Force Institute of Technology's Nuclear Engineering Laboratory. A sketch of the glovebox is illustrated in figure 1.

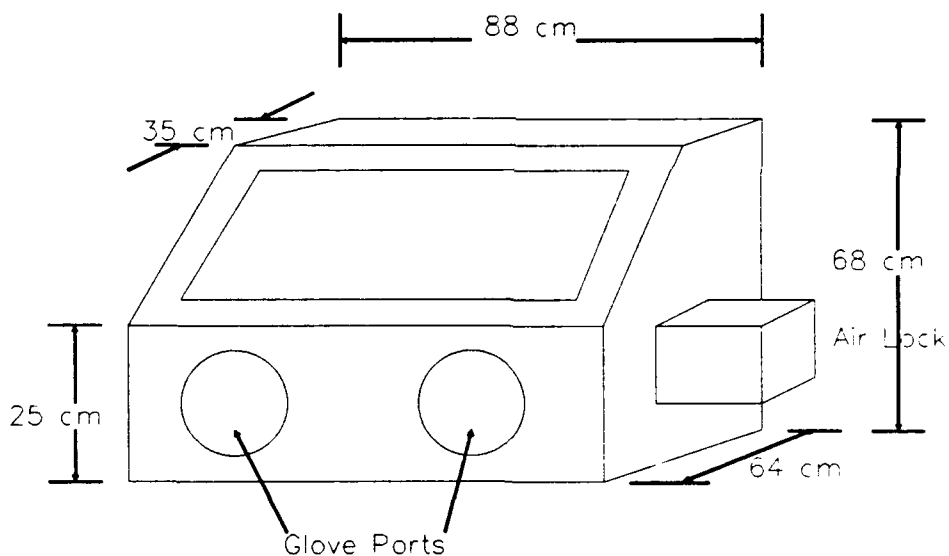


Figure 1. Glovebox and Approximate Dimensions

The glovebox is used as a radon chamber, and an integrated system performs control and monitoring functions of several environmental parameters within the chamber. To control the

temperature, a Neslab temperature-controlled bath is used. The heating or cooling that the Neslab system provides is delivered to the chamber using a radiator with an electric fan forcing air past the radiator. The radon concentration is monitored by a Lucas cell alpha detector with a photomultiplier and an electronic counting system that processes the pulses from the phototube so that the computer can use the information. When the computer detects a drop in radon concentration in the chamber, it commands a radon injector, through an interface, to inject high-activity radon from a reservoir into the chamber to bring the concentration back up to its equilibrium level. Although the relative humidity and barometric pressure are not controlled, they are monitored, and the information is provided to the computer by an environmental monitoring system made by Solomat, Inc. This equipment monitors the temperature in the same way. Figure 2 is a block diagram of the major equipment used.

The following sections describe in detail each of the major components which have just been discussed.

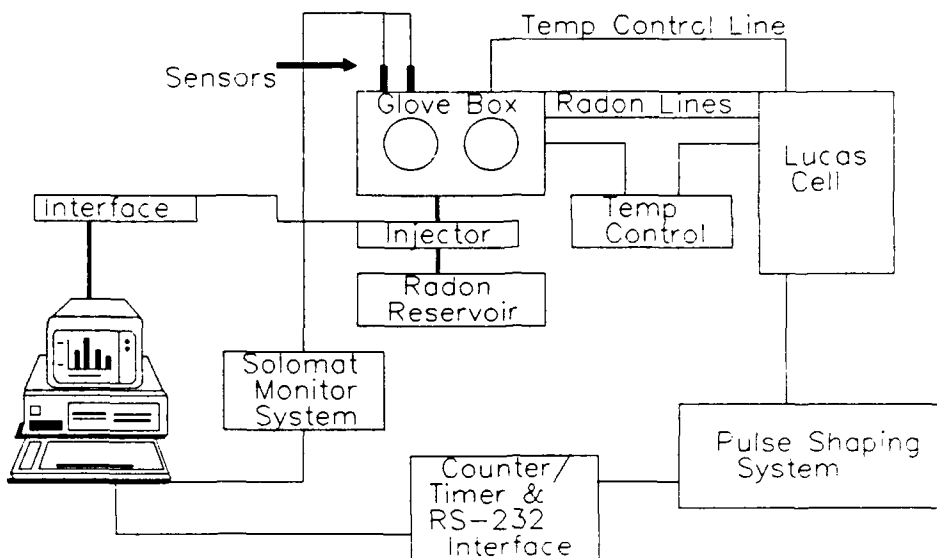


Figure 2. System Major Component Block Diagram

Glovebox

The glovebox that is used as a radon chamber in this project was manufactured by Lab Con Co. It is constructed of fiberglass with a plexiglass window on the front. On one end, there is an airlock through which materials may be passed. The chamber is lit from within by fluorescent lights and has several electrical outlets along the back wall. A number of modifications were made to the chamber to incorporate special features.

The chamber has an intake and an exhaust plenum along the top-front and the bottom-rear of the chamber respectively to allow recirculation of the chamber air and filtering it if necessary. This ventilation system was not needed, but uses

were found for some of the ducting. The front plenum was disconnected from the ventilation system and the Solomat temperature/relative humidity probe was installed in the ventilation inlet, mounted in a rubber stopper. The rear plenum ports were not used at all, and were sealed with lead tape. The ventilation outlet from this plenum was also sealed with a rubber stopper.

The temperature within the chamber is controlled by forcing air across a radiator mounted within the chamber. This assembly is attached to the chamber wall with standoff galvanized brackets. The heating/cooling fluid that circulates through the radiator is passed into the chamber through two flow-through bulkhead fittings installed through the back chamber wall.

A temperature sensor, part of the heating/cooling unit, was mounted into a rubber stopper, and a hole was drilled in the lower left corner of the front wall of the chamber to fit the stopper.

As part of the radon regulation scheme, the air/radon mixture in the chamber circulates past the exhaust port of the radon injector and back into the chamber. The radon injector, located underneath the chamber, is connected to the chamber by fittings through the back wall of the chamber.

A Lucas cell, used to monitor the radon concentration within the chamber, depends on a constant flow of the chamber air through it. Two holes were bored through the top of the chamber, through which nylon tubing was passed and epoxied, providing both an outlet to the Lucas cell and a return line.

The barometric pressure of the chamber is monitored using a Solomat 515BP sensor probe. A nylon tube was inserted through a hole in the top of the chamber and epoxied into place to provide a pressure connection to the sensor probe.

Finally, a 0.1- μ Ci dry ^{226}Ra source in a covered beaker provides the ^{222}Rn environment within the chamber. The beaker is located in the back-left corner of the chamber. The source provides the chamber with a radon concentration of about 120 pCi/liter at equilibrium.

Temperature Control System

The temperature in the chamber is controlled by a Neslab Instruments, Inc. RTE-100 temperature-controlled bath using an analog controller module. This system, as designed, maintains the temperature of the fluid within it at a constant temperature. There are also external connections through which the system can pump the fluid to an external device.

The external fluid lines were routed to the chamber. (The return line from the chamber also flows through a coil around the Lucas cell.) Two flow-through bulkhead fittings pass the fluid into and out of the chamber. Once inside the chamber, nylon-reinforced neoprene lines connect the bulkhead fittings to a radiator mounted on the left chamber wall. A 4-inch electric fan attached to the radiator forces the air past the radiator and improves heat transfer. All of the fluid lines outside the chamber and the Lucas cell are insulated with fiberglass tape wrapped with plastic.

The fluid used in the system was de-ionized water mixed with an equal amount of ethylene glycol. Although freezing temperatures are not anticipated using this equipment, the antifreeze is used to help prevent corrosion and buildup within the temperature-control system.

To control the temperature within the chamber, the temperature sensor, which normally maintains a constant fluid temperature, was removed from the RTE-100 and was installed in the radon chamber. The sensor is attached to the surface of the radiator, and the fan forces the chamber air across it. The two signal wires from the sensor were passed through a rubber stopper placed into a hole in the front chamber wall and were reconnected to the RTE-100.

Radon Reservoir

A 100- μ Ci ^{226}Ra source is used to provide make-up radon whenever the chamber concentration drops. The ^{226}Ra source is dissolved in 4-normal hydrochloric acid in a beaker that is placed within a reservoir. The radon reservoir is a stainless steel cannister with a plexiglass lid. The lid is 3/4 inch thick plexiglass, made where 3/8 inch fits inside of the cannister and 3/8 inch fits on the top edge of the steel cannister as shown in figure 3. The reservoir is sealed by an o-ring between the outside edge of the lower part of the lid and the stainless steel cannister.

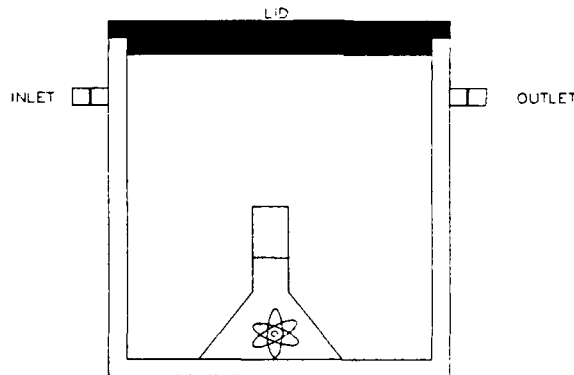


Figure 3. Radon Reservoir

Two quick-disconnect fittings installed in the side of the reservoir allow circulation of the radon past the radon injector inlet and back to the reservoir. This ensures that there will be an adequate supply of radon from the reservoir at the injector. To circulate the radon through this loop, a pump

is used and is operated continually. It contains an electromagnetically-driven rubber diaphragm with a neoprene flapper and operates on 115 Vac.

Because of the 4-normal hydrochloric acid in which the ^{226}Ra is dissolved, there is also a certain amount of HCl vapor within the reservoir. This vapor is circulated through the loop to the injector along with the radon. Although most of the hardware with which this vapor comes in contact is made of stainless steel, a precaution was taken to reduce the HCl content in the gas. In the radon return line between the radon injector and the inlet to the reservoir, a sealed glass jar containing sodium hydroxide pellets forms a trap for the HCl vapor as the gas passes through it. The top of the jar is sealed with a large rubber stopper and two glass tubes pass the gas into and out of the jar.

When ^{226}Ra decays along with most of its progeny, not only are alpha particles emitted, but also gamma rays as high as 1.12 MeV from ^{214}Bi . To reduce the radiation environment around the radon chamber work area, the radon reservoir was placed directly beneath the radon chamber and was then shielded with lead bricks.

Radon Injector

When the radon concentration within the radon chamber drops for any reason, it is necessary to transfer some radon from the radon reservoir into the radon chamber. This must be done very precisely because of the high concentration of the radon within the reservoir. Adding only 1 cm³ of radon from the reservoir can raise the concentration in the chamber by as much as 8 pCi/liter.

I designed a radon injector which was fabricated by the AFIT Fabrication Shop. Figure 4 shows a schematic diagram of the injector pneumatic system, and figure 5 is a photograph of the injector. The injector basically consists of a motor-driven gas syringe, that can operate on two separate environments, determined by two solenoid valves. The injector is controlled by the Z248 computer through a special interface. Upon the appropriate command from the computer, the injector pulls or pushes the syringe and opens or closes one of the solenoid valves. These actions can be performed in any sequence desired, including simultaneous operation of the solenoid valves and the syringe control. The sequence and timing of these operations is controlled by the computer using the radon control program (RCP).

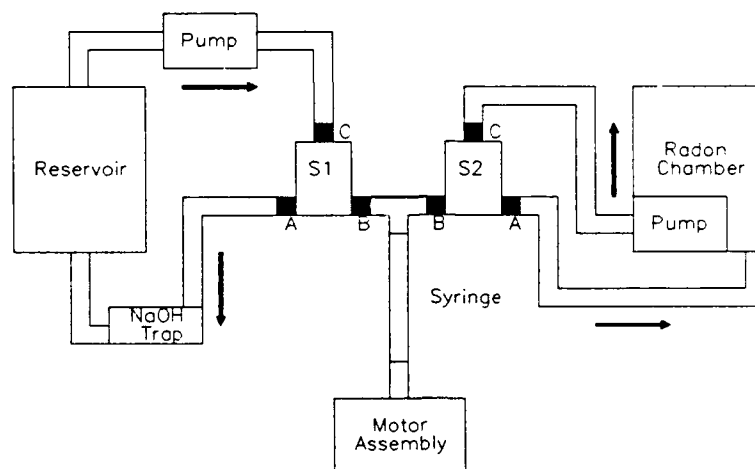


Figure 4. Radon Injector Pneumatic System

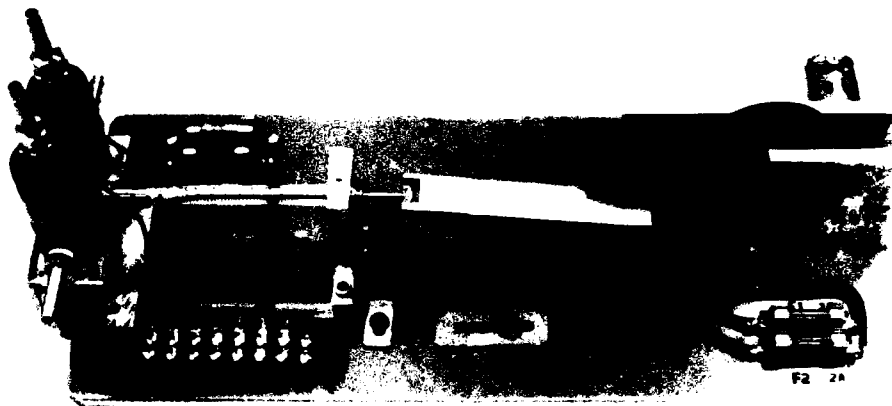


Figure 5. Radon Injector

The assembly was constructed on 1/4-inch aluminum plate. The terminal block and the four fuseholders were epoxied into place. Figure 6 shows a schematic electrical diagram of the interface. The fuses protect the lines coming into each of the solenoid valves carrying +12 volts of direct current (Vdc) and the motor voltage lines to one side of the motor. The syringe plunger travel is adjustable using inner and outer limit switches that are operated by an actuator pin which also attaches the injector pushrod to the syringe. The travel of the syringe is adjusted such that the syringe volume is 0.2 cm³.

The motor that draws and pushes the syringe using two reduction gears is a 12 Vdc reversible motor. The syringe itself is a high-pressure gas syringe manufactured by Precision Sampling Corporation and has a volume from 0.0 to 1.0 cm³. The syringe is attached between two solenoid valves by a T-fitting. These solenoid valves operate at 12 Vdc and have 3 ports each. Referring to figure 4, when a solenoid is de-energized, port B of the solenoid valve is sealed off completely, but the valves are open from port A to port C. This allows the two pumps to continuously circulate the gases through the reservoir loop and the radon chamber loop with the solenoids de-energized.

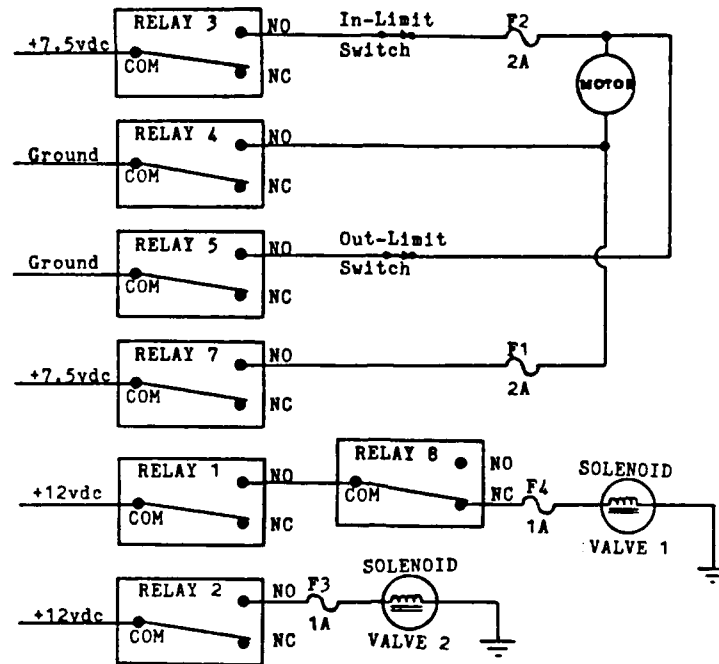


Figure 6. Electrical Schematic Diagram of Radon Injector

When a transfer of gas from one loop to the other is desired, the solenoid for that loop is energized. This seals port C and opens the valve from port A to port B. The syringe can now draw a volume of the gas through the open valve. After drawing the syringe, the valve can be closed and the other one opened. This allows the syringe to express the gas it contains into the new loop. Once the syringe is expressed, the now open valve can be closed and the gas transfer is complete.

It is important that the two valves not be opened at the same time. The reservoir is a sealed system and is therefore subject to changes in pressure with respect to the chamber,

which is at ambient barometric pressure. If the valves were opened simultaneously with the reservoir at a lower pressure than the chamber, then the reservoir would draw chamber air into it and the reservoir radon supply would be diluted. On the other hand if the reservoir were at a higher pressure, then a volume of radon from the reservoir would be expelled into the chamber, and a surprisingly large increase in chamber radon concentration would occur.

Although the injector motor is rated at 12 Vdc, the voltage that is supplied to it through the interface is only 7.5 Vdc. This is because the motor must stop when it reaches the in-limit switch. At voltages higher than 7.5 Vdc, the motor gains too much speed and momentum carries the final drive gear too far. This causes the limit-switch actuation pin which is driven by the gear to begin moving back off the limit switch, and the injector malfunctions.

Injector Interface

Control of the radon injector by a computer requires the use of a special interface that can accept commands from the computer. A parallel computer port was chosen for communication with this type of interface because of the relative ease with which commands can be sent through the port. The Z248 is configured for two parallel ports, with the first, LPT1,

selected as the printer port. The radon control program was written such that the radon injector interface is addressed through the second parallel port, LPT2. This port can be directly addressed in BASIC using the "OUT port,x" command, where port is the address in memory of LPT2 in this case, and x is the code that is to be sent through the port. This is discussed in greater detail later in this chapter.

The LPT2 port is an eight-bit parallel communications port and its address in the Z248 memory is 278 (hexadecimal) or 632 (decimal). Since the port in this application is used for one-way communication only, the communication protocol is much simpler than that which would be required for duplex communications.

The interface is connected to the LPT2 port such that any data sent to it by the computer is latched into the interface unconditionally, meaning that the computer does not require any kind of acknowledgement signal from the interface. This is done by connecting pin 10 of the parallel port to ground, creating a low signal on the acknowledge line into the computer. This lets the computer know that the device connected to the LPT2 port is unconditionally ready to receive data. Table 1 lists the pin allocations for the Z248 parallel ports.

PIN NUMBER	SIGNAL NAME
1	Strobe
2	Data Bit 0 (DATA1)
3	Data Bit 1 (DATA2)
4	Data Bit 2 (DATA3)
5	Data Bit 3 (DATA4)
6	Data Bit 4 (DATA5)
7	Data Bit 5 (DATA6)
8	Data Bit 6 (DATA7)
9	Data Bit 7 (DATA8)
10	Acknowledge
11	Busy
12	Page end
13	Select
14	Auto feed
15	Error
16	Initialize Printer
17	Select input
18-25	Ground

Table 1. Parallel Port Definitions (6:5.12)

The signal at the LPT2 port at any given time can contain a code from 0 to 255, based on the 8 data lines that convey all the data to and from the port. Table 2 summarizes the LPT2 data lines and their addressing.

A schematic diagram of the injector interface is shown in figure 7. The device is basically an 8-channel, digitally-controlled relay system. The interface is designed to use the digital output on the eight data lines from the computer's LPT2 port to control eight single-pole, double-throw relays.

DESIGNATION	BINARY REPRESENTATION	DECIMAL REPRESENTATION
DATA1	2^0	1
DATA2	2^1	2
DATA3	2^2	4
DATA4	2^3	8
DATA5	2^4	16
DATA6	2^5	32
DATA7	2^6	64
DATA8	2^7	128

Table 2. Parallel Port Data-Line Addressing

The power requirement for the interface is 12 volts direct current (Vdc). The relays require 12 Vdc for the coil voltage, but the rest of the circuit only needs +5 Vdc. The +5 Vdc secondary voltage is supplied to the interface on the circuit board itself using a solid state +5 Vdc regulator (VR1). The +5 Vdc output of the voltage regulator provides the power for the octal buffer amplifier, IC1.

Buffer amplifiers fundamentally provide isolation between two devices while still coupling them together. This can be especially important when interfacing computers. In the design for the radon injector interface, the buffer amplifiers couple the eight data lines of the LPT2 port of the computer to eight relay control circuits, but they prevent the current loops in

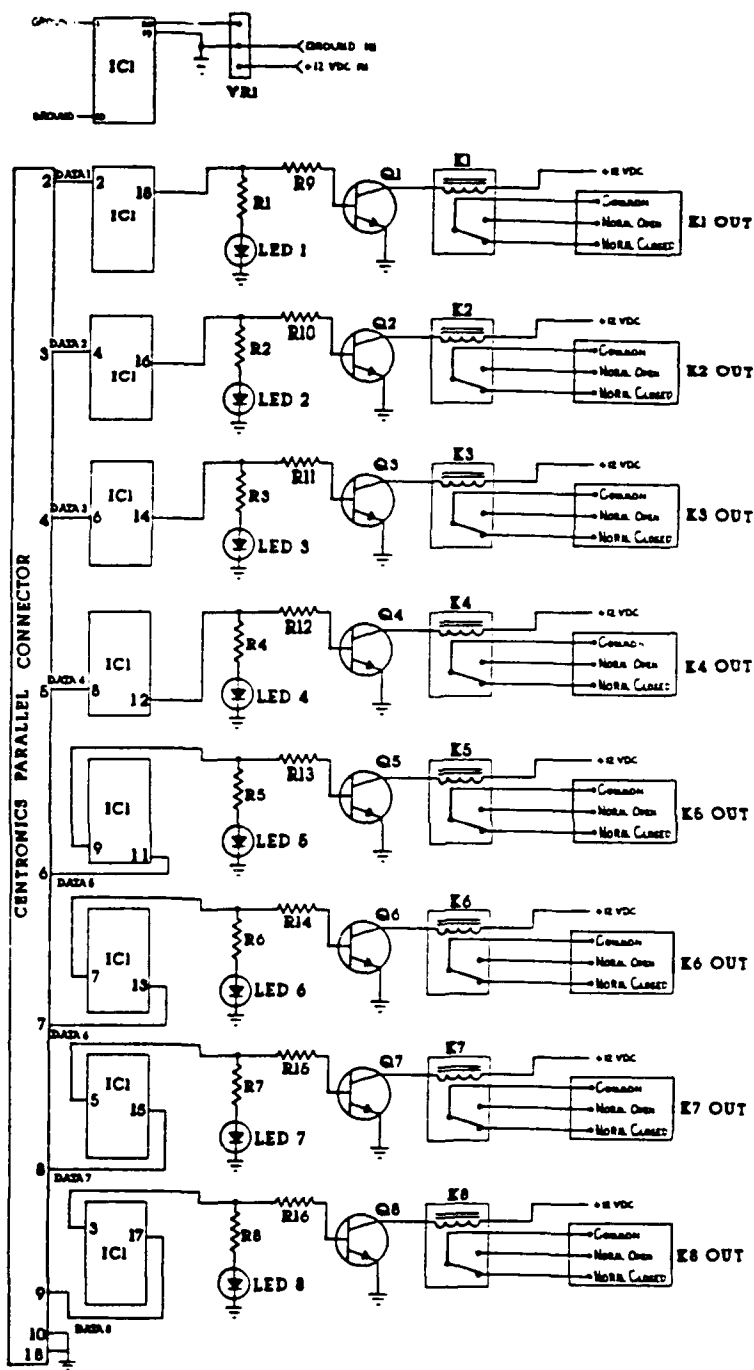


Figure 7. Radon Injector Interface Schematic Diagram

the relay circuits from drawing current back through the data lines of the LPT2 port itself, which could cause severe damage to the port.

The octal buffer amplifier in the interface, a 72LS244 integrated circuit (IC), has eight separate channels on the same IC. The interface uses each of these eight channels to control a separate relay circuit (3:41). Thus, the interface has eight circuits that are all identical, and a discussion of one will be a discussion of them all. The channel that controls relay 1 is described below.

There are ten connections between the LPT2 computer port and the radon injector interface. Pins 2 through 9 of the interface Centronics connector are connected to the DATA1 through DATA8 lines of LPT2 respectively. They are the interface data control lines. Pins 10 and 18 are connected to the interface ground. Pin 10 is the acknowledge line for LPT2. By grounding pin 10, the low voltage signals the computer that the interface is unconditionally ready to receive any data from the port. The ground at pin 18 ensures that the voltage levels in the interface have the same reference as those in the LPT2 port.

To follow this description of the operation of channel 1, refer to figure 7. The command to energize relay 1 originates

in the computer. In most instances, the computer will determine which code needs to be sent to the interface, but codes can be sent at the command of the user as described in Appendix D, Radon Control Program Description. The command that energizes this circuit is "OUT 632,1". This causes the voltage on the DATA1 line of LPT2 to go high while the other data lines are kept low.

The voltage on pin 2 of IC1 is coupled through the first stage of the octal buffer amplifier to pin 18. The positive voltage on pin 18 causes current to be drawn through LED1 and R1, a 330-ohm current-limiting resistor, developing a voltage at pin 18 of IC1 across LED1 and R1. The current through LED1 causes it to turn on, indicating that channel 1 of the interface is active. The voltage developed at pin 18 of IC1 is coupled through a 1000-ohm coupling resistor, R9, to the base of Q1, a 2N3904 NPN switching transistor. The voltage on the base of Q1 causes it to draw current from the +12 Vdc supply through the coil of relay K1 to its grounded base.

The current flowing through the coil of K1 energizes the relay, closing the contacts between the common and the normally-open terminals. These terminals are completely separate from any control circuitry in the interface. Likewise, if the application calls for it, the normally closed contacts can be used, and energizing the relay can de-energize the

application. The relays are effectively digitally-controlled switches, and can switch either alternating or direct currents of up to three amperes.

A double-sided printed circuit board was designed to mount and connect the components of the interface. Figures 8 and 9 show the solder and the component sides of the circuit board. Figure 10 is the view of the circuit board from the component side, showing the component layout.

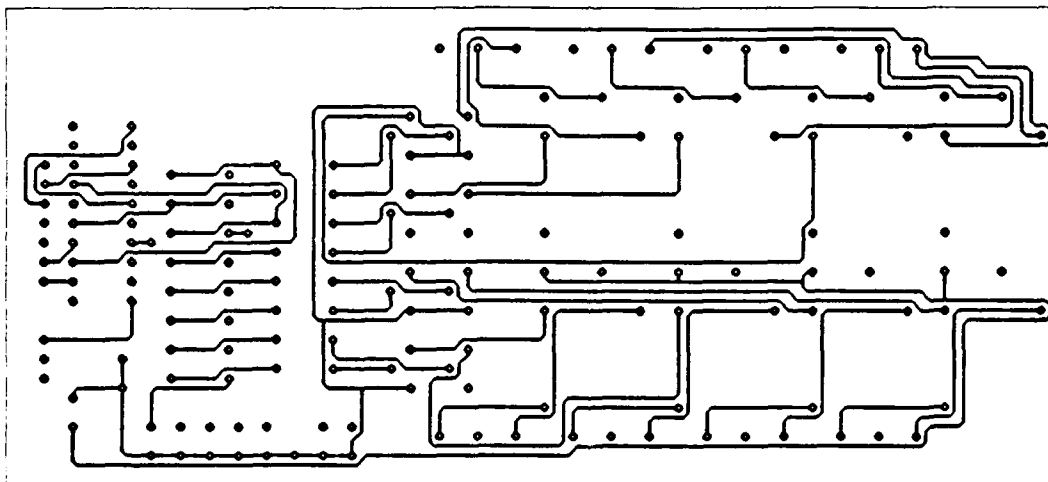


Figure 8. PC Board for Injector Interface
Solder Side

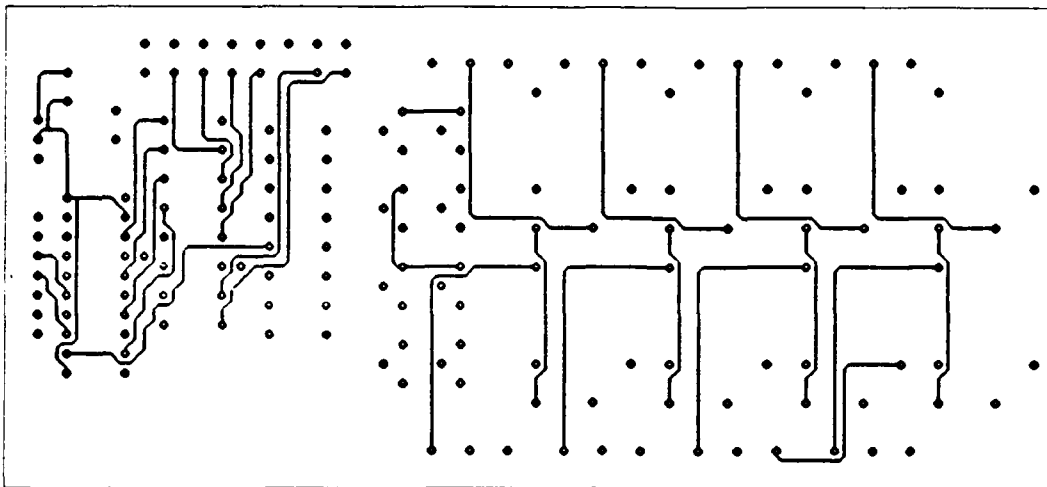


Figure 9. PC Board for Injector Interface
Component Side

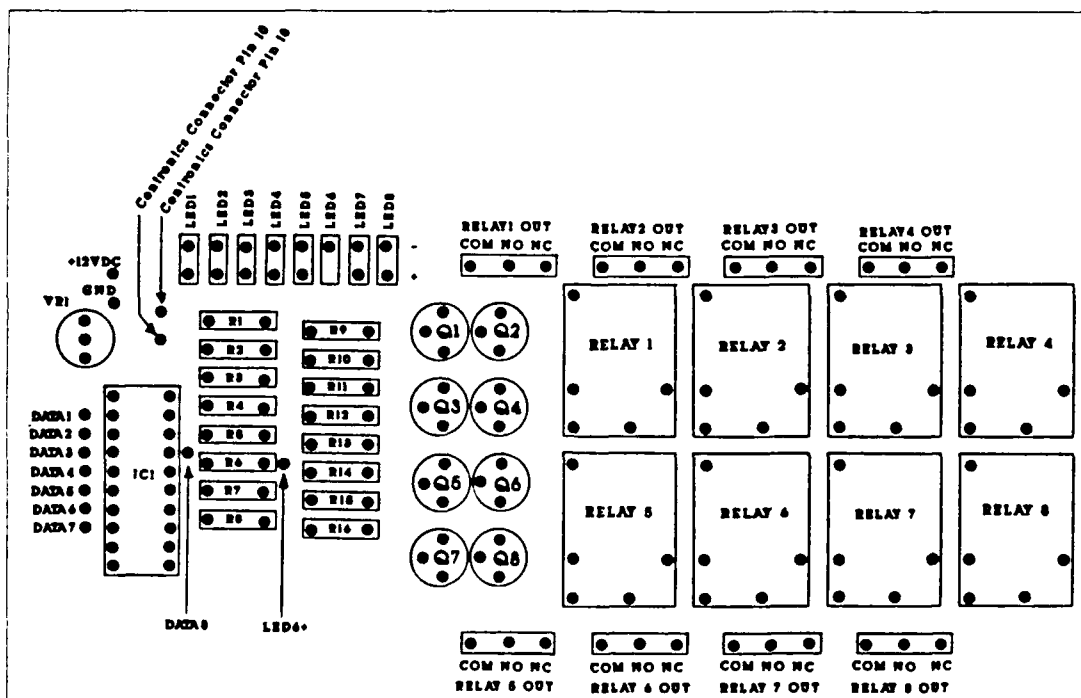


Figure 10. Component Layout for Radon Injector Interface

The interface is housed in a 3" x 5" plastic experimenter's box. The corners of the circuit board are notched to fit the inside of the box. A 25-conductor ribbon cable makes the connection between the interface and a Centronics connector that mates with a standard parallel printer cable from the Z248 computer. The connections on the printed circuit board for the LEDs and the relays are made using single-conductor copper insulated wire. The LEDs are mounted in the front face of the interface box and are labeled 1 through 8. The relay connections are made to three terminal strips on the back of the box. The top strip is the connection point for the common terminals of the relays, designated K1 through K8. The terminals on the center strip are the normally open connectors, and the terminals on the bottom strip are the normally closed connectors. The 12 Vdc power for the interface is supplied through a red (+) and a black (-) binding post, also located on the back of the interface box.

Table 3 lists the system component which each channel of the interface controls. Details about the specific wiring for the radon injector interface can be found in Appendix A, Equipment Setup.

Relay	System Component
1	+12 Vdc to solenoid valve 2
2	+12 Vdc to solenoid valve 1
3	+12 Vdc to motor when pushing syringe
4	-12 Vdc to motor when pushing syringe
5	-12 Vdc to motor when drawing syringe
6	Not used
7	+12 Vdc to motor when drawing syringe
8	Solenoid 1 disconnect relay

Table 3. Circuits Controlled By Radon Injector Interface

Lucas Cell

The radon concentration in the radon chamber is monitored by a modified Lucas cell. This device is a scintillation detector that is designed to detect alpha particles (4:680). It consists of a PVC cylinder, 20 inches in length, with a thin layer containing ZnS[Ag] on the inside wall of the cell (5:36-39).

The Lucas cell has two air lines into it through which the air from the radon chamber is circulated. The chamber air is pumped by an electromagnetically driven, rubber-diaphragm pump with a neoprene flapper that operates on 115 Vac.

In an effort to keep the temperature of the Lucas cell reasonably stable, a wooden box was built to house it, lined with 2-inch thick styrofoam. A 1/2-inch diameter copper tube was wound in four turns around the Lucas cell inside the box. The fluid returning from the chamber temperature control system is routed through this coil on the way back to the Neslab RTE-100. Although the Lucas cell still has some slow swings in temperature, it is somewhat isolated from the sometimes large temperature changes that occasionally occur in the laboratory area.

As in any refrigeration application, condensation can occur on the copper line surrounding the Lucas cell. To prevent this from being a problem, several precautions were taken. First, the Lucas cell was wrapped in plastic to seal it against moisture. Secondly, a galvanized pan was fabricated to fit in the bottom of the box. The edges of the pan were sealed with silicone to prevent any moisture from getting around and underneath the pan. Lastly, a drain was attached from one side of the pan to the outside of the box. A drain pan was placed underneath the drain to accumulate and evaporate any condensate from the box.

Pulse-Shaping System

The output pulses from the Lucas cell are very small, random amplitude pulses. To be useful, the pulses must be amplified and shaped in such a way that a counter can recognize each transmitted pulse. Figure 11 is a block diagram of the equipment that is used for this purpose in the radiochemistry laboratory itself.

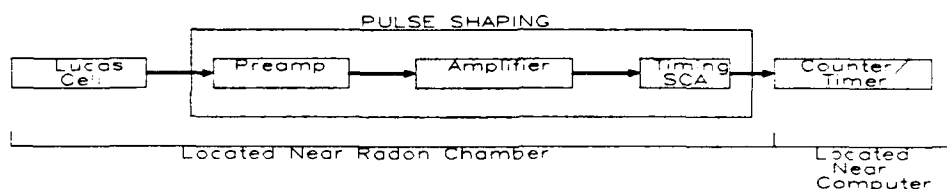


Figure 11. Pulse Shaping System

Counter/Timer

The pulses from the pulse shaping system are coupled via a 100-foot coaxial cable, terminated with a 50-ohm load, to an Ortec counter/timer located beside the computer workstation. This counter/timer has an RS-232 option added whereby it can communicate directly with the Z248 computer. The counter/timer is connected to the computer's COM1 serial port, and is addressed using a baud rate of 300, no parity, 8-bit word length, and one stop-bit.

Communication with the counter/timer by the computer is simple. It recognizes a number of commands which need only

to be written by the computer to the COM1 port using the "PRINT #A,B\$" command, where A is the file opened by the computer for communication, and B\$ is the phrase to be sent. Each time a command is sent to the counter, it sends a response to the computer. This response is a data string that reflects the status of the system after receiving the command. If the command was one requesting information, the information will be sent to the computer first, followed by the status. Regardless of whether the actual information being transmitted to the computer is numeric or otherwise, it is always sent in the form of a data string. Numeric information must be extracted from the string by the computer.

The counter/timer status is sent via a 9-digit numeric code. There are two codes which indicate the system is functioning normally. When power-up has just occurred, the first three digits of the code are "001", indicating a normal power-up condition exists. At any other time, the status code should end with the digits, "69". This code indicates the command was executed successfully. Table 4 lists the commands that the radon control program uses to communicate with the timer/counter and the response that the computer receives.

Every three minutes, the computer executes a series of commands requesting the number of counts from the counter/timer and converts that number into radon concentration information.

COMMAND	RESPONSE 1	RESPONSE 2
INIT	Status string	None
START	Status string	None
STOP	Status string	None
SHOW_COUNTS	Count string	Status string
CLEAR_COUNTER	Status string	None

Table 4. Ortec Counter/Timer Communication Strings (1:16-17)

Environmental Monitoring System

The system that controls the temperature in the radon chamber, discussed earlier in this chapter, is a stand-alone system, providing heating or cooling, as needed, to the chamber. However, the system does not send temperature information to the computer workstation. An environmental monitoring system made by Solomat is used to provide information to the computer on temperature, relative humidity and barometric pressure.

The Solomat instrument is a computer device that has two separate modules: an MPM4013 Environmental Module, and an MPM4000 Matrix Processor. The environmental module unit receives the electrical signals from sensor probes and converts them into the data of interest. The matrix processor converts the information into the output format desired, and also has an LCD display that can be used for instrument programming or for data display. In this application, information on the

environmental parameters that are being monitored is not only displayed on the LCD, but is also transmitted through an RS-232 interface to the COM2 serial port of the Z248 computer.

Communications are conducted at 9600 baud, using no parity, 8-bit word length, 1 stop bit, and with the data set ready (DS) parameter turned on. The matrix processor sends data through the RS-232 interface as though it were sending it to a printer. Turning on the DS parameter enables the matrix processor to continuously send data so that the computer can read it at its convenience.

The environmental module has two sensors plugged into it. The probe attached to socket 1 is the PT100 probe, providing temperature and relative humidity information. The second probe, plugged into socket 2, is the 515BP probe, which gives barometric pressure data. The matrix processor, once programmed properly, sets up three data channels, one to read each environmental variable. It cycles through these three channels continuously, reading the data from the environmental module and then providing the data as output to the computer through the RS-232 interface.

The process of programming the Solomat matrix processor is not straightforward, and an explanation of that process is not in order here. However, the step by step process to

accomplish the programming, in case the need arises, is described in detail in Appendix E, Solomat MPM4000 Programming. The unit has a 3-volt lithium battery which maintains the unit's memory when it is turned off or when it loses normal operating power. However, if the lithium battery is removed for any reason, or if it runs down, the matrix processor program will be lost when the unit is turned off, and reprogramming will be necessary.

There are two ways to program the matrix processor: by direct keyboard entry on the unit or by using the CS4 computer software developed by Solomat, Inc. It is easier by far to use the CS4 software to do the programming; its use is described in Appendix E.

Zenith Z248 Computer

The Zenith Z248 computer that is used as the control center for this system is configured with MS-DOS 4.01 and GW-BASIC 3.22. An EGA or VGA monitor is required for the display because of the high-resolution graphic screen modes that the radon control program (RCP) uses. A hard drive is necessary for the automatic data-logging feature to work and also for automatic system reboot capability in case of a temporary power failure.

Four communication ports are used on the computer: two serial ports and two parallel ports. Normally the Z248 computer

does not come equipped with a second standard serial port, so one was added to the system. The COM1 serial port communicates in duplex with the Ortec 996 Counter/Timer, providing counting information from the Lucas cell. The COM2 serial port communicates in duplex mode with the Solomat MPM4000 matrix processor, providing temperature, relative humidity, and barometric pressure information on the chamber. The first parallel port, LPT1, is used as a normal parallel printer port. The second parallel port, LPT2, is used for simplex communication with the injector interface.

An EGA monitor is used as the display for the computer. The radon control program, which simultaneously manages all the equipment in this project, generates a high-resolution display of the chamber parameters that are being controlled and monitored. Appendix D, Radon Control Program Description, goes into considerable detail on the complete function of the program and the details of the display.

A problem which arises occasionally is the loss of power in the laboratory. To counter that problem, the computer was configured and the software was designed such that in case of a power failure, a minimum of data is lost, and once power is restored, the system is able to reboot itself completely.

Femto-Tech Radon Detector

During the development of this project, it was necessary to establish a firm relationship between the number of counts received from the Lucas cell and the radon concentration within the chamber. A Femto-Tech radon detector was used to provide this information.

The Femto-Tech system has two basic modules, a radon sensor and a portable computer. The radon sensor includes an ion chamber, an LCD count indicator, and its own battery power. This module was placed inside the radon chamber, and its output was coupled out of the chamber to the portable computer. The portable computer, a Sharp PC-2500, runs a program to convert the data from the sensor module into radon concentration information. The computer provides real-time concentration data as well as an average over a 24-hour period. At the end of the 24-hour period, the built-in printer/plotter generates a plot of the concentration over the last 24 hours, taken at 30-minute intervals. The average concentration over the period is also plotted across the graph. After the plot is generated, the computer automatically begins taking data on the new 24-hour period.

While the Femto-Tech system was measuring the radon concentration within the chamber, the count rates measured by

the Lucas cell were simultaneously monitored and recorded. After taking data over a wide range of radon concentrations for an extended period of time, a correlation between the monitored count rate and the radon concentration within the chamber was established. This correlation is presented and discussed in chapter 3.

III. Experiments Performed

Several experiments were performed in the design of the radon injection system to explore and quantify certain characteristics of the radon chamber, the radon reservoir, and the Lucas Cell detector. The equilibrium concentration of the radon chamber is a parameter that can lead to the determination of the radon chamber's effective volume. The equilibrium concentration of the radon reservoir is also a necessary parameter in determining how much concentrated radon must be injected into the radon chamber to make up for a drop in concentration in a given situation.

The response of the Lucas cell to a change in radon concentration is a key factor in determining what kind of algorithm to use to regulate the radon concentration in the radon chamber. When the radon concentration within the chamber drops, the equilibrium of the ^{226}Ra source with radon and its progeny is upset, and the count rate that the Lucas cell detects may not be a true indication of the new concentration until equilibrium in the system is reestablished. To complicate matters further, the exchange rate of the air between the Lucas cell and the radon chamber slows down the response time even more.

To explore this behavior, experiments were conducted to determine the time required for a change in concentration in the radon chamber to be correctly measured by the Lucas cell. The following sections describe these experiments, as well as others, which were performed to characterize the radon control system.

Calibration of the Automatic Counting System

The relation of counts from the Lucas cell to radon concentration was obtained by comparison of the counts with the concentration measured by the Femto-Tech detection system. It is assumed that the calibration factor provided with the Femto-Tech is accurate.

Over a period of nine days, 180 one-hour counts were made with the Lucas cell at the same time that the Femto-Tech system was monitoring the chamber concentration. The resulting calibration curve is shown in figure 12. The calibration equation was determined by using a least squares regression with the counts as the independent variable and the radon concentration as the dependent variable. The calibration equation was determined to be:

$$\text{concentration} \left(\frac{\text{pCi}}{\text{liter}} \right) = \text{counts per 60 minutes} * 0.001246 - 1 \quad (1)$$

The derived coefficients were 0.001246 ± 0.000013 and -1 ± 1 for the variable and constant coefficients respectively. Concentrations calculated using this equation should be correct to within 2.8 pCi/liter.

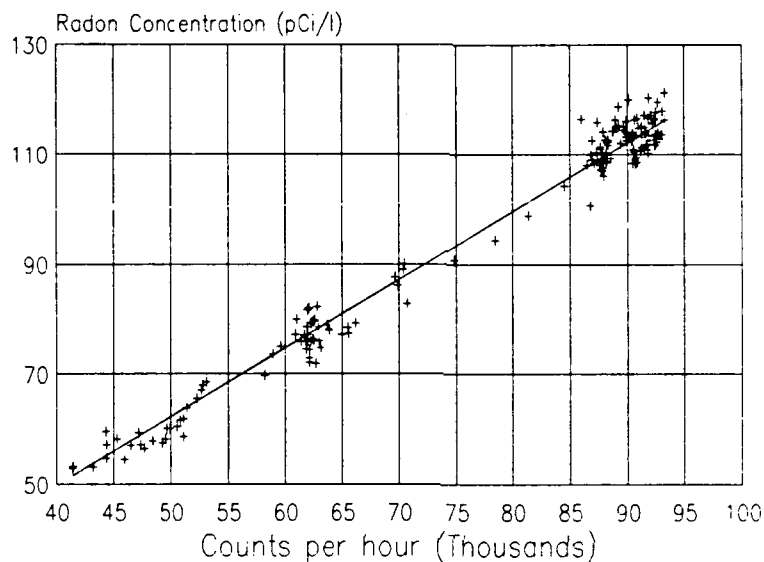


Figure 12. Lucas Cell Calibration Plot

The data collected in this experiment also provided information on the effective volume of the radon chamber system which is used to develop the protocol for radon injection. The radon concentration within a volume is determined by the equation:

$$\text{concentration} = \frac{\text{activity}}{\text{volume}} \quad (2)$$

or

$$\text{volume} = \frac{\text{activity}}{\text{concentration}} \quad (3)$$

The Femto-Tech measured an equilibrium radon concentration of about 120 pCi/liter in the radon chamber produced by the decay of the 0.1- μ Ci ^{226}Ra source. By dividing the activity, 0.1 μ Ci, by the concentration, 120 pCi/liter, the effective volume of the chamber system was determined to be approximately 830 liters. This figure can vary somewhat due to the rubber gloves in the front of the chamber which can change the volume, but the addition or subtraction of two or three liters on the calculations that will be used to control the chamber radon concentration will have little effect.

The physical volume of the radon chamber is approximately one-half of the effective volume because of the delay in emanations of the radon from the dry radium source. The ^{226}Ra exists as a dry salt of RaCl_2 , coating the sides and bottom of a one-liter glass beaker. The top of this beaker is covered with a Microsorban filter to allow radon gas to diffuse out of the beaker. Thus the crystals of RaCl_2 , although very

small, and the filter paper impede the release and transport of radon and reduces the equilibrium concentration by a factor of:

$$\frac{V_{actual}}{V_{effective}} \approx \frac{350}{830} \approx 0.4$$

Experiments to Explore A Step-Decrease In Radon Concentration

Two experiments were performed to characterize the behavior of the Lucas cell in response to a step-decrease in radon concentration within the chamber. In each case, the radon chamber was allowed to reach an equilibrium concentration of about 120 pCi/liter before the experiment was performed.

The experiments began by opening the large door of the radon chamber for several seconds to allow some radon to escape the chamber and be exhausted through the laminar-flow hood in the laboratory. The Z248 computer, using the radon control program, was used to control the counting system and provide data every three minutes on the counts detected by the Lucas cell.

Figure 13 is a plot of the results of the two experiments. An initial sharp decrease in the count rate of each data set is clearly seen, followed by an asymptotic approach to a new

count rate. Because an identical volume of radon was not removed from the chamber in the two experiments, no correlation was expected between the two final levels that were ultimately reached.

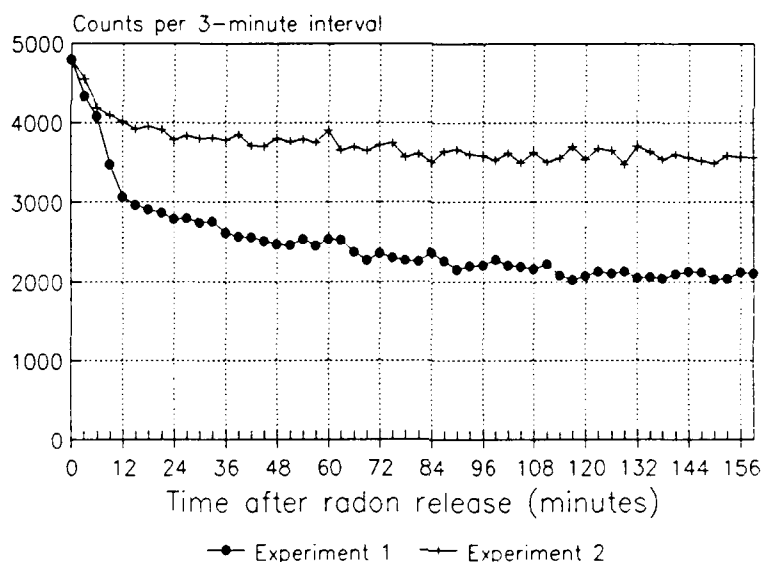


Figure 13. Response to Step-Decrease in Radon Concentration

It is important to realize at this point that the asymptotic decrease in count rate for a period of two hours does not indicate a decreasing radon concentration in the chamber. This slow decrease occurs because time is required for the radon in the Lucas cell to be completely mixed with the lower radon concentration in the chamber and for the radon and its progeny to reach nuclear equilibrium.

Several important results were obtained from the experiments that were performed. First of all, the Lucas cell

did not indicate the true concentration level until about two hours after the change in concentration occurred. Secondly, the percentage of the initial drop in the count rate with respect to the stabilized count rate was nearly the same in each experiment. Figure 14 clearly illustrates this. Although the radon released was different in each experiment, the percentage of the total ultimate drop in concentration as a function of time is virtually the same in both cases.

When a step-decrease in radon concentration occurs, the total drop which will occur cannot be measured until the counting system stabilizes after about two hours. However, by the fourth time period, T4, the rate of decrease of the counts accumulated each three minutes changes to a slower rate. With respect to the total drop in concentration which will finally be measured, by T4 the concentration has dropped 70 percent from the original level and another 30 percent drop remains. To get a more reliable value for this 70-percent-drop point, the counts for T5, T6, and T7 are averaged.

This is an important pattern. The radon control system is designed to regulate the radon concentration within the chamber. But the system can only respond to a detectable, measurable, and predictable decrease in the count rate. When the condition exists where radon regulation needs to occur, it should be done as soon as possible, and a wait of 120 minutes

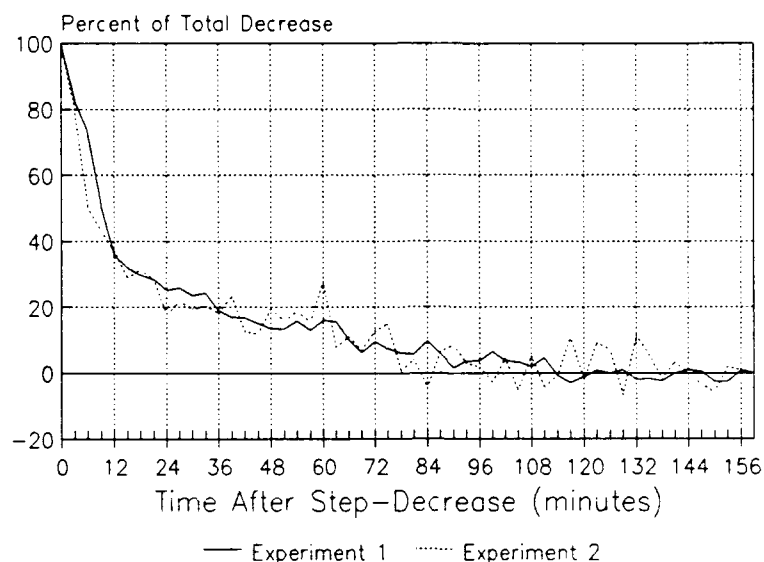


Figure 14. Percentage of Total Decrease in Count Rate

to take corrective action to a radon deficiency is unacceptable. However, figure 14 shows that after only 21 minutes, it is possible to predict with reasonable accuracy what the final count rate will be when the counting system stabilizes after a step-decrease in concentration. The decrease in count rate at 21 minutes is about 70 percent of the final total drop in count rate. Based on this premise, the radon control program can make adjustments to the radon concentration in 21 minutes to correct a low radon level that would otherwise have not been fully measured for another 100 minutes. The details of the logic used to regulate the radon based on these results is discussed in more detail in chapter 4 as well as the algorithm used to correct for a gradual decrease in concentration.

Experiments to Explore A Step-Increase In Radon Concentration

Two other experiments were conducted to observe the response of the counting system to a step-increase in the concentration of radon in the chamber. This is an important facet of the ultimate goal of regulating the radon concentration since this determines how fast the counting system can respond to an injection of concentrated radon into the chamber. The experiments were carried out by first allowing the counting system to stabilize at a low concentration in the chamber, and then radon was injected into the chamber from the reservoir.

The radon concentration in the third experiment was about 78 pCi/liter. Using the radon injector, 2.4 cm³ of radon from the reservoir were transferred into the chamber. In the fourth experiment, the radon concentration was about 91 pCi/liter, and 4.4 cm³ were injected into the chamber. Figure 15 shows how the counting system responded to the increase in concentration for the two experiments.

It is obvious that the trends are similar in both experiments, and the counting system in both cases appears to stabilize after about two hours. To explore the similarities further, figure 16 compares the percentage of the increase

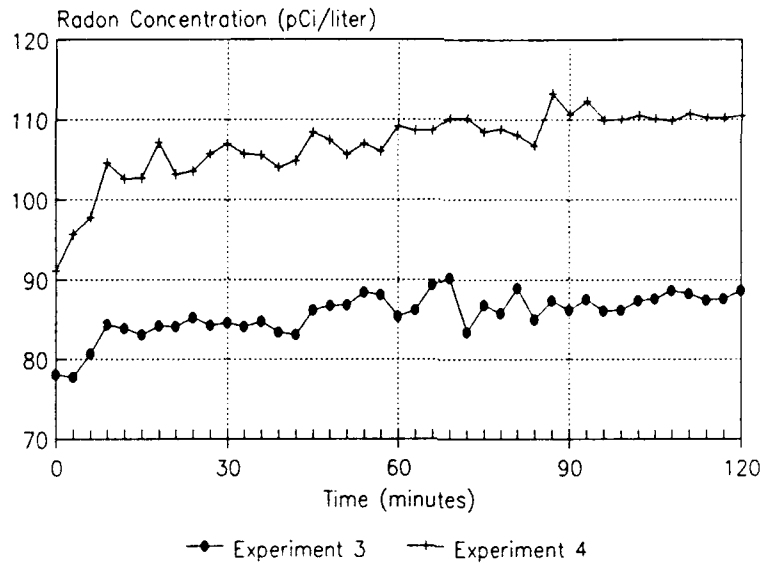


Figure 15. Response to Step-Increase in Radon Concentration

that the counting system will eventually reach. Considering the statistical fluctuations of the data, there is virtually no difference between the two trends.

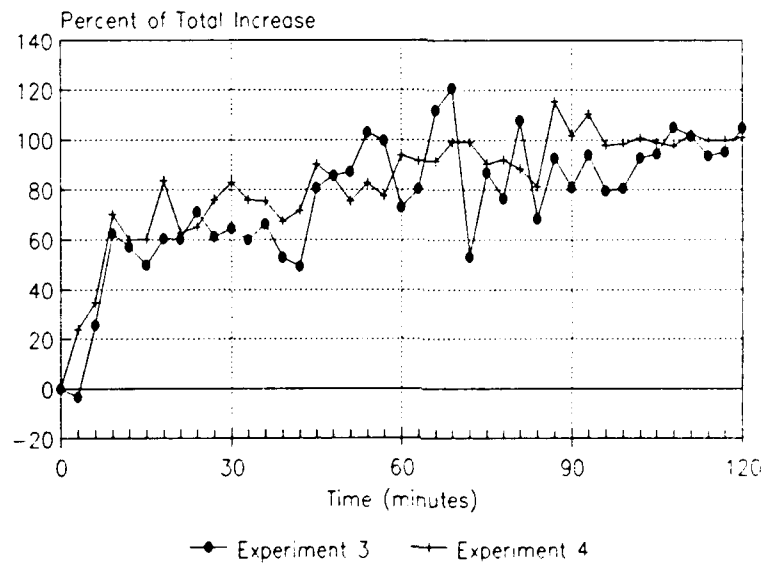


Figure 16. Percentage of Total Increase in Count Rate

These experiments show that a step-increase in radon concentration in the chamber causes the Lucas cell to respond with a partial increase in count rate within only a few minutes. Furthermore, the count rate stabilizes after approximately two hours. The application of this result to the control of the radon concentration within the chamber is that once make-up radon is transferred from the reservoir to the chamber to compensate for a drop in radon concentration, two hours must elapse before any further action may be undertaken to bring the concentration back up to normal.

Determination of Effective Decay Constant in Chamber

When the ^{226}Ra source within the radon chamber undergoes radioactive decay, ^{222}Rn is produced, which then decays to ^{218}Po , and so on until the stable element ^{206}Pb is reached. Since the half-life of ^{226}Ra is 1600 years and that of its progeny, ^{222}Rn is 3.83 days, secular equilibrium will be achieved in about one month. Thus in a closed chamber containing $0.1\ \mu\text{Ci}$ of ^{226}Ra , in the absence of any decays except those due to the release of radon gas, the total activity of the ^{222}Rn in the free volume of the chamber will be $0.1\ \mu\text{Ci}$.

The differential equation that describes the change in the number of radon atoms with respect to time is:

$$\frac{dN_2}{dt} = \lambda_1 N_1 - \lambda_2 N_2 \quad (4)$$

where the subscripts 1 and 2 refer to ^{226}Ra and ^{222}Rn respectively, and λ is the decay constant for each radionuclide. Using the initial condition that when $t=0$, the number of radon atoms, N_2 is also zero, equation 1 can be solved in terms of $N_2\lambda_2$, the activity of the radon:

$$N_2\lambda_2 = \frac{\lambda_1 N_1^0 \lambda_2}{\lambda_2 - \lambda_1} (e^{-\lambda_1 t} - e^{-\lambda_2 t}) \quad (5)$$

Equation 6 can be reduced and solved in terms of the activity of radon, A_2 :

$$A_2 = \frac{A_1^0 \lambda_2}{\lambda_2 - \lambda_1} (1 - e^{-\lambda_2 t}) \quad (6)$$

This is not exactly the situation that exists, however, inside the radon chamber because of form of the source within its beaker along with the Microsorban filter which covers the beaker. The radium source inside the chamber is in a covered beaker. This means that when a ^{226}Ra atom decays to ^{222}Rn , it will not be free to enter the chamber until it diffuses out of the radium source and through the Microsorban filter. The result is that the radon build-up rate inside the chamber is reduced by some factor. This additional buildup time can be

included in equation 7 by subtracting a term, D' , that is related to the diffusion coefficient, D , from the exponential coefficient:

$$A_2 = \frac{A_1^0 \lambda_2}{\lambda_2 - \lambda_1} (1 - e^{-(\lambda_2 - D')t}) \quad (7)$$

While data were being collected to calibrate the counting system with the actual concentration in the radon chamber, an opportunity to examine the build-up rate of radon within the chamber presented itself.

Over a period of more than 12 days, the chamber was left undisturbed while the radon concentration increased from about 80 to 120 pCi/liter, due only to the radioactive decay of the ^{226}Ra source within it. The Femto-Tech radon detection system monitored this increase and recorded the data. Figure 17 shows graphically the exponential growth of the concentration.

The decay constant for ^{222}Rn is 0.1813 day^{-1} . The continuous curve drawn through the data in figure 17 is a least-squares approximation to the exponential curve that best fits the data. The decay constant for the curve is 0.1488 ± 0.0001 per day. The difference between the two constants is D' , which, in this case, was determined to be $0.0325 \pm 0.0001 \text{ day}^{-1}$.

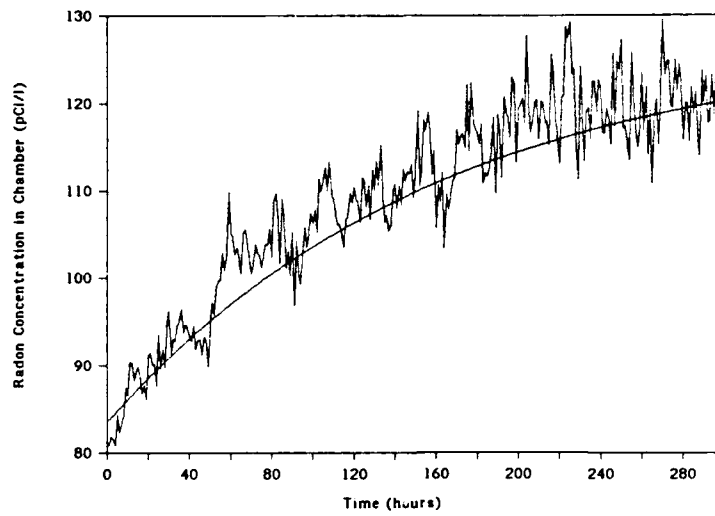


Figure 17. Concentration Increase Due to Source Decay

IV. Radon Concentration Control

Theory

The experiments that were performed to characterize the behavior of the radon control system in response to certain conditions have already been discussed. Based on the results of those experiments, there are two conditions that the radon control program recognizes and takes corrective action against: either a step decrease or a gradual decrease in the radon concentration. The process that occurs following a step-decrease in concentration will be discussed first, followed by an explanation of the procedure to correct a gradual decrease.

Recall that when the radon chamber experiences a step-decrease in radon concentration, the counting system responds almost immediately with a sharp decrease in the count rate. By the seventh time period, 21 minutes after the initial drop is detected, the count rate falls about 70 percent of the total drop that will ultimately be reached if no corrective action is taken. The radon control program (RCP) uses this level to predict the total drop in radon concentration that has actually occurred and makes adjustments to the radon level accordingly.

To correct the radon concentration in this situation, several steps are required. First, the RCP must correctly discern that a radon concentration deficiency in the radon chamber actually exists. Secondly, when a deficiency does exist, the RCP must wait until the seventh time cycle (21 minutes) to predict the true radon concentration level. The RCP then injects make-up radon into the chamber based upon the prediction. Finally, after injection has occurred, a cycle of "dead-time" must pass during which no further injection action must be undertaken. This allows the counting system to stabilize at the new equilibrium.

The RCP needs to discern when a real drop in radon concentration has occurred. By the very nature of radioactive decay alone, the number of counts that the Lucas cell will detect over a 3-minute period will fluctuate statistically. It is therefore necessary to design the system so that occasional low counts will not trigger the injection sequence.

When the chamber is at equilibrium, the radon concentration is approximately 120 pCi/liter. This corresponds to about 4800 counts per three-minute period. By Poisson statistics, one standard deviation is the square root of 4800 or about 69 (2:40-43). Three standard deviations below 4800 would be 4592 counts, a 4.3 percent drop. This means a three-minute count of 4592 could still conceivably be just a statistical

fluctuation and not a low radon condition. For this reason, the setpoint below which the RCP determines that the chamber has a low radon concentration is set below 4592. The actual setpoint that was designed into the system was 4560 counts, five percent below the equilibrium count rate.

It was shown in chapter 3 that when a step-decrease in radon concentration occurs, 70 percent of the drop will be seen by the counting system in about 21 minutes. The remaining 30 percent of the total drop takes about 100 minutes more. Furthermore, a similar time scale was observed upon injection; the majority of the increase in count rate occurs within a short time, and the count rate stabilizes within about 2 hours. It is these characteristics upon which the algorithm for maintaining the radon concentration is based.

Description of Radon Regulation Subroutine in Radon Control Program

The radon regulation subroutine can be found in Appendix C, Radon Control Program Listing, lines 4000 to 4290. The program listing contains a cursory explanation of almost every line of code, but this section explains the structure of the subroutine and what it does as a unit of code.

The main loop of the RCP branches to the radon regulation subroutine every three minutes (see line 610 of RCP),

immediately after calculating the radon concentration for the 3-minute cycle just ended. If the number of counts for the last period is less than 4560, then a flag is set called LOWRDN. This first low count is designated here as the count at time T1. To keep track of the time that this subroutine detected the low radon condition, a counter called LOWPASS is set equal to 1 and will be incremented every time the program branches to this subroutine while the RCP evaluates the low radon condition. The system is now warned that a low radon condition may exist and the program returns to its normal function until the next 3-minute cycle is ended.

When the next cycle branches to the radon regulation subroutine, it obtains the new count rate for the period ending at T2 and averages it with the count rate at T1. If the average is below the setpoint of 4560 counts, then the system determines that a low radon concentration situation really does exist and commits itself to trying to adjust the concentration accordingly. A new flag called LOWLEVEL is set to indicate this condition. If the average of the counts at T1 and T2 are not below the set point, such as would be the case if the count at T1 were just an isolated low count and the T2 count was normal, then the system would clear the LOWRDN flag and reset all variables in the subroutine.

When the LOWLEVEL flag is set, the radon regulation subroutine will store the counts for T3 through T7. It has been previously discussed that the average of the counts at T5 through T7 represents about 70 percent of the drop that has actually occurred in the chamber. Therefore, after the count at T7 is stored, the counts at T5, T6 and T7 are averaged. This average is then subtracted from 4800, the equilibrium count rate. The result is the number of counts per cycle by which the count rate is low, but this is only 70 percent of the true deficiency. Therefore the number of counts by which the count rate is low is multiplied by $10/7$ to predict what the total deficiency will be if the counting system stabilizes with no radon injection.

The number of counts by which the count rate is low can now be correlated directly to the number of injections that need to be made to correct the low radon condition. Multiply the number of counts for the three-minute period by 20 so that equation 1 can be used to convert counts to pCi/liter. The effective volume of the chamber is approximately 830 liters. By multiplying the concentration that needs to be made up by 830 liters, the result is the number of pCi that need to be injected into the chamber to bring the concentration back up to equilibrium.

When the number of picocuries of radon that each injection transfers into the chamber is known, the number of injections needed can be found by dividing the number of picocuries needed by the number of picocuries per injection. This number is not likely to be an integer. Because the radon injector can not perform fractional injections, the fractional part of the number is dropped and the resulting integer is the number of injections which will be performed. The number of injections that the RCP has determined need to be performed is called DEFINJ.

The system is now ready to inject radon from the reservoir into the chamber. Each injection performed takes about 14 seconds to complete, and the program takes about 15 seconds to process all the necessary information before it is ready to inject. The number of injections performed at one time is limited by the 3-minute cycle of the system. If injections are being performed when the system is due to reset the counter, the counter will not get reset. As a result, the next time the counter is read, the indication will be approximately twice what it should read. If the injections extended perhaps across two 3-minute cycles, the result would be even worse. To eliminate this problem, only 10 injections can be performed during each 3-minute cycle. If there are more injections that

need to be performed, then they will be done during the next cycle, and the next, and so on, until all are done.

After the injections have taken place, about two hours will have to elapse before the counting system stabilizes. For this reason, the program cannot be allowed to try to execute any more concentration adjustments until this time has transpired. To accomplish this, after the last injection has been completed, a flag is set called SPINCYCLE. While this flag is set, each time the main loop branches to the radon regulation subroutine, a variable called SPINMINUTES is incremented by 3. SPINMINUTES corresponds to the number of minutes that the SPINCYCLE has been running. After SPINMINUTES reaches 120, then the SPINCYCLE flag is cleared, all flags and variables in the subroutine are reset, and the program is again free to look for a low radon condition and take whatever action is appropriate.

There is only one parameter that calibrates this RCP routine with the radon injection system: the number of picocuries of radon which the injector transfers to the radon chamber each injection. The parameter is simple to determine.

The autoinjector should be turned off and the radon chamber door opened for a second or two to let some of the radon escape. The counting system will take about two hours to equilibrate,

following which the system should be left alone for two more hours so a good estimate of the radon concentration, calculated over a full 60 minutes, can be determined by the RCP. By performing several injections and then waiting for about four hours to let the system stabilize, the number of picocuries per injection can be calculated as follows:

$$\frac{\text{picocuries}}{\text{injection}} = \frac{\text{increase in concentration (pCi/l)}}{\text{number of injections}} * 830 \text{ liters} \quad (8)$$

By placing this number in line 4260 of the RCP as the number of picocuries per injection, the main autoinject function of the RCP should be calibrated. Based on the experiments performed in this thesis, this number was found to be 1395 (pCi/injection).

Procedure to Adjust a Gradual Decrease in Radon Concentration

The previous discussion explains how the RCP treats a step-decrease in radon concentration in the chamber. However, a step-decrease is not the only mechanism by which the radon concentration can drop. A procedure was incorporated into the RCP that allows for adjustment of the radon concentration when it gradually decreases, such as might be the case if a charcoal cannister were inside the chamber slowly absorbing radon.

The equilibrium concentration of the radon chamber is 120 pCi/liter, corresponding to about 4800 counts every three minutes. Although the 3-minute counts will fluctuate statistically, the concentration, as determined by the total number of counts collected during each total hour, should not vary nearly as much. Without any fluctuations, the counts detected during 20 3-minute periods should be about 20×4800 , or 96,000 counts. Three standard deviations below this level would be 95,070 counts, corresponding to a concentration of 118.5 pCi/liter, 1.5 pCi/liter below the equilibrium level (2:40-43). Therefore, when a 60-minute count falls below 95,070, then there is a very low probability that this is the result of statistical fluctuations; it will be due to a low radon concentration in the chamber.

This procedure bases its action only upon the total counts that have been accumulated during the previous hour. Also, if the program has not been running for a full hour, or if an automatic injection has occurred within the past two hours, this procedure will not be executed. This ensures that adjustments of this type will only be made when the system has been running long enough to have accumulated counts for a full hour and that the counting system has had adequate time to stabilize after any automatic injection procedures.

The procedure is a very simple one, once its timing is correctly set up. It consists of one line of code in the RCP, line 2290. In this line, if the total number of counts accumulated during the last hour falls below a predetermined setpoint that is more than three standard deviations below the normal number of counts, then radon needs to be injected into the chamber to bring the concentration back up to normal.

In determining what number of counts should be used for the setpoint in line 2290, the number of picocuries per injection should first be calculated as just described above. The setpoint can be determined by the following equation:

$$\text{count setpoint} = \frac{\left(120 \frac{\text{pCi}}{\text{l}} - \frac{\left(\frac{\text{number of pCi}}{\text{inj}} \right) (1 \text{ inj})}{830 \text{ l}} \right)}{0.001246 \frac{\text{pCi}}{\text{liter-count}}} \quad (9)$$

Once the count setpoint is known, it is included in line 2290 of the RCP. This is the only calibration that this routine requires. Since the number of picocuries per injection was determined to be 1395 pCi/liter, by equation 9 the count setpoint is 94,960 counts, which is more than three standard deviations below the normal count. Now if the total number of counts over a period of an hour is less than 94,960 counts, which corresponds to 118.3 pCi/liter, line 2290 will cause one injection of radon to be performed. The data that was acquired

to calibrate the system indicates that one injection of reservoir radon increases the chamber concentration approximately 1.7 pCi/liter. Therefore, this procedure should raise the concentration in the chamber back up to the 120 pCi/liter level.

V. System Performance

The performance of the overall system to monitor/control the environmental parameters in the radon chamber is constantly monitored on the system's computer screen. Figure 18 is a photograph of the monitor, taken on January 31, 1991.

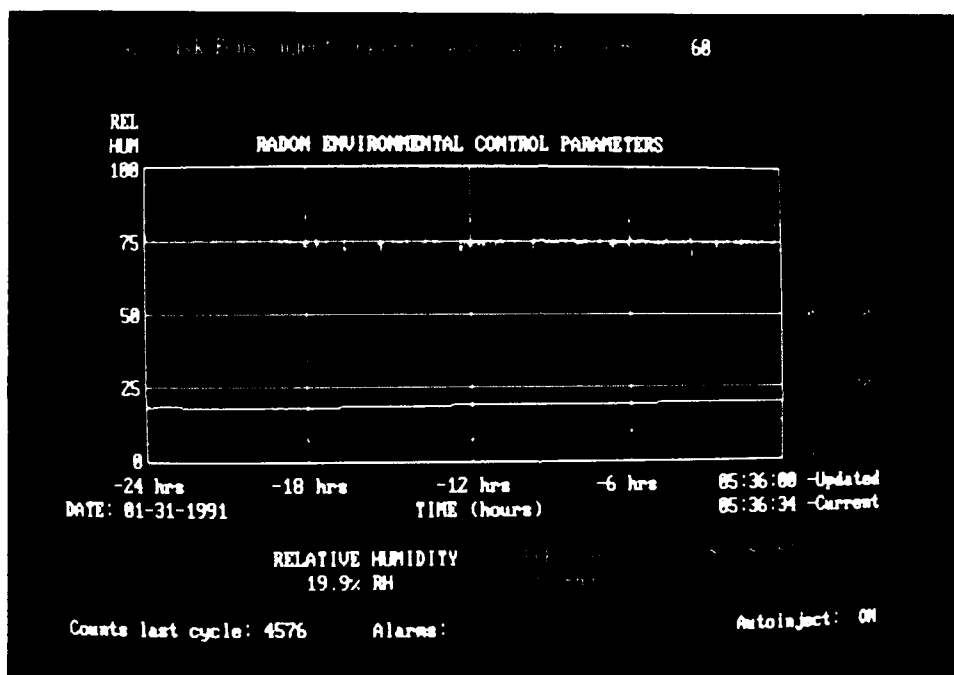


Figure 18. Computer Screen Showing System Performance

The temperature, relative humidity, and barometric pressure as monitored by the Solomat environmental monitoring system are shown on the screen, showing changes as conditions changed over the previous 24 hours. The data plotted at the right-hand

side of the screen reflect current conditions in the radon chamber. The specific value of each parameter is also shown at the bottom of the screen. The performance of the temperature control system using the Neslab temperature-controlled bath can be seen as the temperature changes. The inability of the system to maintain a constant temperature was attributed to the system not having the heating/cooling capacity to compensate for extreme temperature changes in the laboratory.

The ability to regulate the radon concentration within the chamber was well demonstrated. Figure 19 shows how the concentration of the radon chamber changed when six charcoal cannisters were placed within the chamber to absorb radon. During this experiment, the automatic injection system was turned off, and the chamber concentration was allowed to drop. After about 23 hours, the automatic injection was turned back on, and the system returned the chamber concentration to normal.

Another experiment was conducted with six charcoal cannisters except that the automatic injection was left turned on. Figure 20 shows how the system performed to maintain the radon concentration at about 120 pCi/liter. The vertical lines across the radon concentration plot show when injections were performed.

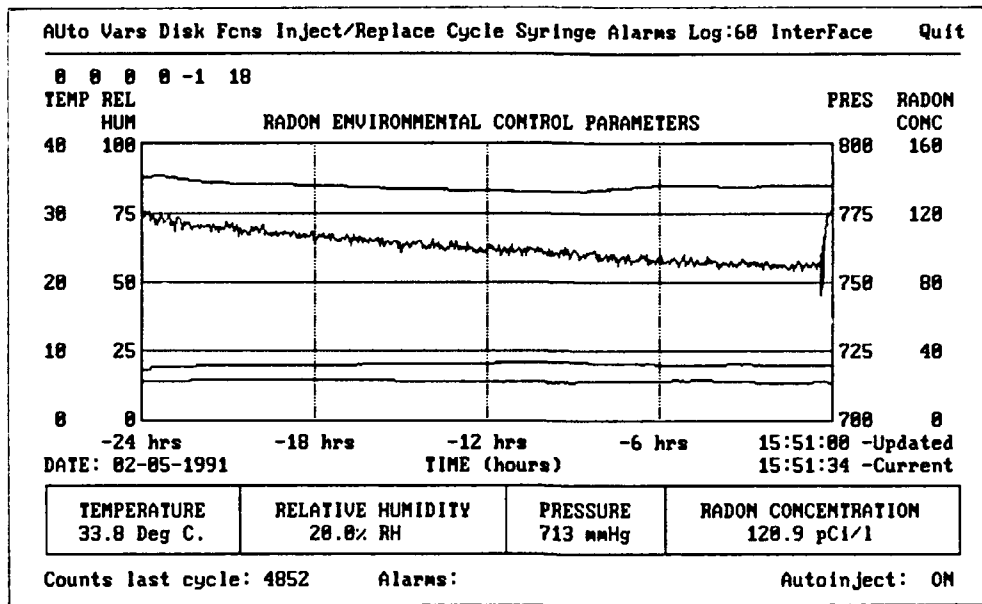


Figure 19. Radon Decrease Due to Charcoal Absorption

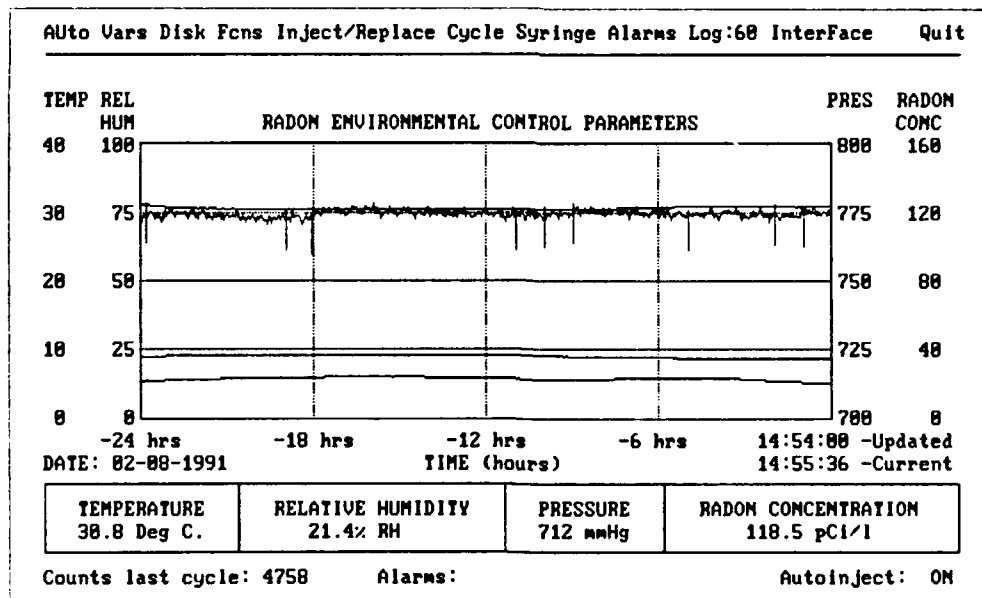


Figure 20. Radon Regulation Performance

Figures 19 and 20 show vividly how well the system works, and that the desired goal of maintaining the radon concentration at about 120 pCi/liter under circumstances that would normally reduce the radon concentration has been achieved.

VI. Possible Future Refinements

Although the radon control system works well and has many useful features, there are still other refinements that can be made to the system to improve its performance or utility. Some possibilities are presented here for consideration.

A useful improvement to the RCP would be to write it in a different language. The memory constraints involved with using GW-BASIC created the need for extreme care in using program features to prevent interference with the RCP in performing its necessary functions at each 3-minute cycle. If the program were compiled using QuickBASIC, the memory constraints would be removed, and additional features could be added to the program to constantly watch the system clock and let the RCP take over whenever a 3-minute cycle is due.

Other algorithms could also be looked at to provide radon regulation over other scenarios than were provided for in the RCP presented in this thesis.

The Solomat environmental monitoring system could possibly be improved by moving the PT100 temperature/relative humidity probe to a location that would make it more responsive to the environmental conditions inside the chamber. An ideal placement would be in the left chamber wall directly behind the cooling system fan.

Before the chamber is used for research involving the temperature and relative humidity parameters, the PT100 sensor probe should be calibrated. The operator's manual for the Solomat system prescribes a method to do this.

The temperature control system has been configured to operate as well as possible with the RTE-100 temperature-controlled bath. However, the chamber temperature does not stay constant as the laboratory temperature changes. There are four further modifications that could be made to further stabilize the chamber temperature. First, the radon chamber could be insulated on all sides except for the front and the right side with the airlock. Second, a digital controller module for the RTE-100 could replace the analog module. This would provide improved control capability along with the ability to plug an extra temperature sensor into the module instead of removing the standard one from the bath and placing it into the chamber. Third, heat transfer within the chamber could be increased by adding another fan or even a larger radiator. If these modifications still do not bring the temperature stability within acceptable limits, the heating/cooling capacity of the RTE-100 is just not high enough to adequately control the temperature. A temperature-controlled bath with a higher capacity could solve this problem.

During the development of the radon chamber system, it was discovered that the air pump which had long seen service within the radon chamber was completely inoperative. Age and possibly the chamber environment had destroyed the pump. The system now has two pumps of the same type: a dual pump inside the chamber, and a single pump in the radon reservoir loop. These pumps should be checked periodically to determine their serviceability.

A modification to the radon injector and injector interface could prevent a particular problem from arising. As has been discussed, energizing solenoid valves 1 and 2 simultaneously opens an unobstructed path for radon from the reservoir to flow into the chamber if the pressure in the reservoir is higher than the chamber. There is a condition under which the Z248 computer tries to energize both of these valves at once. If the power to the computer is turned off by the operator, all of the interface address lines go high, energizing all eight relays in the interface. To make sure that valve 1 does not energize under this circumstance, the +12 Vdc from relay 1 must pass through the contacts of relay 8. Because the connection to relay 8 is made through the normally-closed contacts, when all the relays energize, the connection to valve 1 is broken at relay 8. However, this does not prevent an operator from accidentally energizing both valves using the

manual interface control of the RCP. To be completely sure that valve 1 can energize only when valve 2 is de-energized and vice-versa, another relay could be wired into the valve 1 power wire at the injector that would disconnect power from valve 1 anytime valve 2 had power applied.

One final modification would be to the Z248 computer. The keyboard is especially sensitive to any accidental keypresses because many of the keys are active function keys. If a keyboard lock were placed into the computer so that the keyboard could be turned off when not in use, accidental keypresses could prevent unexpected program malfunctions. This could be a hardware lock or a software lock.

Appendix A

Equipment Setup

The environmentally controlled chamber developed during the course of this project uses a number of diverse pieces of equipment, some of which were designed specifically for this system. This section will briefly describe the setup of the equipment.

The equipment is separated into two physical locations: the radiochemistry laboratory and the computer workstation room. The wiring distance between these two locations is about 100 feet. A sketch of the equipment in the radiochemistry laboratory is shown in figure 21.

The following list of equipment is located in the radiochemistry laboratory:

- glovebox
- temperature control system
- radon reservoir
- radon injector
- Lucas cell and phototube
- electronics for scintillation counting

The computer workstation room contains the following equipment:

- Zenith Z248 personal computer system
- Solomat environmental-monitoring system
- Ortec 996 Counter/Timer
- radon injector interface
- 12 Vdc power supply for radon injector interface
- 7.5 Vdc power supply for radon injector interface

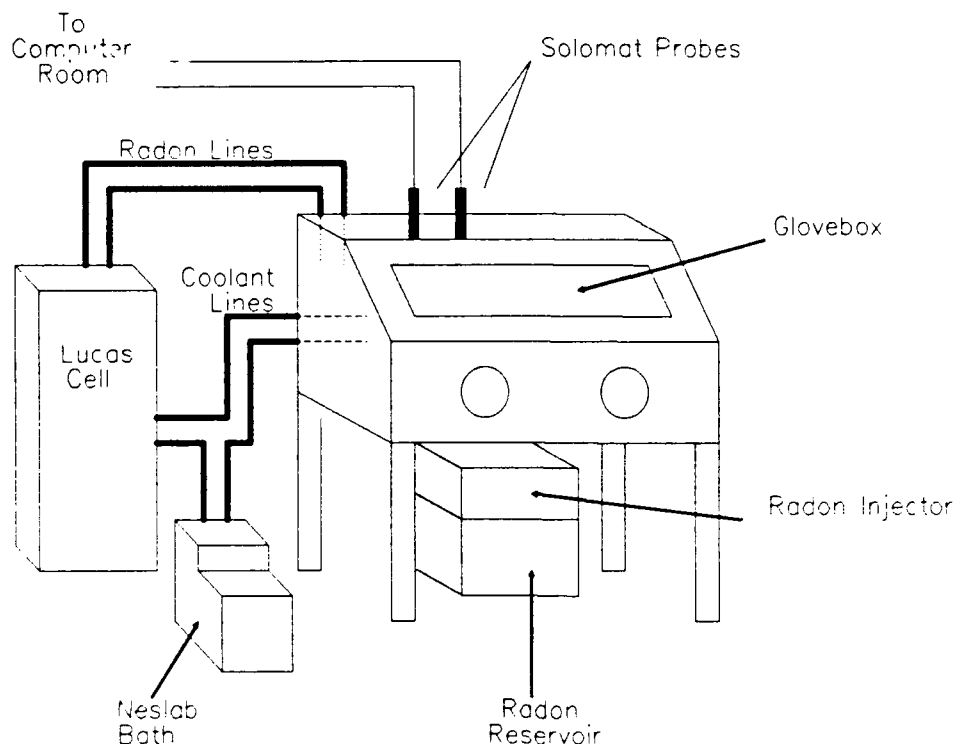


Figure 21. Equipment Setup in Radiochemistry Laboratory

Glovebox

The two Solomat sensor probes are installed in the top of the glovebox to sample the air inside the chamber. The PT100 probe supplies temperature and relative humidity signals, and the BP515 probe generates the barometric pressure signal. Flow-through fittings provide connections from inside the glovebox for the radon lines to the Lucas cell and the cooling/heating lines.

Radon Reservoir

The radon reservoir is placed directly underneath the table supporting the radon chamber and is shielded by lead bricks. The reservoir has two quick-disconnect fittings attached to it through which the radon is circulated to the radon injector. All radon connections are made using Tygon tubing.

Radon Injector

There are both pneumatic and electrical connections to the radon injector. The pneumatic lines contain radon circulated both from the reservoir and from the radon chamber. The electrical connections are the control voltages from the radon injector interface.

The electrical connections to the radon injector are all made to the radon injector interface which is located at the computer workstation. A 100-foot length of 15-conductor telephone cable is used to connect the two. The wires in the cable are color-coded, and the terminals on the interface are identified by the color of the attached wire. The color wire which should be attached to each terminal is marked beside each terminal on the interface in permanent ink. Table 5 lists the color of each wire and the circuit to which each is related.

WIRE COLOR	CIRCUIT
Black/White stripe	Ground for solenoid valves
Orange/Black stripe	+12 Vdc for solenoid valve 2
Green/Black stripe	+12 Vdc for solenoid valve 1
Black	7.5 Vdc (+/-) for motor circuit
Orange	7.5 Vdc (+/-) for motor circuit
Green	7.5 Vdc (+/-) for motor circuit
Red	7.5 Vdc (+/-) for motor circuit

Table 5. Wiring Connections to Radon Injector Interface

Temperature Control System

A Neslab RTE-100 temperature-controlled bath is the temperature controlling unit. The unit has a built-in pump for circulating the fluid to external devices. The fluid from the pump outlet is routed first through the glovebox, then through the Lucas cell, and finally back to the pump inlet.

The temperature sensor was removed from the Neslab unit and was placed inside the radon chamber, mounted directly to the radiator. The two wires from the sensor are coupled through the front of the radon chamber and are connected to the two wires coming from the RTE-100 to which the sensor was originally wired when the sensor was internal to the unit.

Lucas Cell

The Lucas cell is housed in a plywood box, lined with 2-inch styrofoam. A coil of half-inch diameter copper tubing is wound around the Lucas cell through which the temperature-control fluid passes. A galvanized pan collects any condensate from the coil and a drain carries it out of the box to evaporate in a pan.

The output of the Lucas cell is connected to a preamplifier which is connected directly to the output of the Lucas cell at the base of the unit inside the insulated box.

Pulse-Shaping System and Counter/Timer

The system that amplifies and conditions the pulses from the Lucas cell is composed of several separate modules: a preamplifier which is located in the insulated box with the Lucas cell, an Ortec model 485 amplifier, and an Ortec model 420A timing single-channel analyzer. To monitor the system's performance, but not a part of the pulse-shaping system, is a Canberra model 1772 counter/timer. All of these modules, except for the preamplifier are mounted in an MT Nuclear NIM bin on the laboratory countertop beside the radon chamber. Refer back to figure 11 for a block diagram of this system.

An Ortec model 996 Counter/Timer, located beside the Z248 computer, is used to provide counting information from the pulse-shaping system to the computer through an RS-232 interface. The RS-232 connector in the back of the counter/timer is connected to the COM1 port of the computer using a cable with standard 9-pin DIN connectors. The counter/timer is controlled completely by the computer.

Solomat Environmental Monitoring System

The Solomat MPM4000 Matrix Processor and the MPM4013 Environmental Module are located beside the Z248 computer, and long extension cables connect the sensors with the environmental module. The PT100 sensor probe is connected through the extension cable to socket 1 of the MPM4013, and the 515BP probe is connected to socket 2.

The Solomat system comes equipped with a cable to connect the MPM4000 to a personal computer, and the connection between the COM2 port of the Z248 computer and the MPM4000 is made using this cable.

Because the Solomat system must be operated continuously, power is provided to the MPM4000 using an AC-to-DC adapter that is provided with the system.

Zenith Z248 Personal Computer

The Zenith Z248 personal computer is set up normally by connecting the EGA monitor and the keyboard. Four connections are made to the input/output ports in the back of the computer.

1. An Epson LQ-1000 printer is connected to the LPT1 parallel port.

2. The radon injector interface connects to the LPT2 parallel port using a standard Centronics printer cable.

3. The Ortec 996 Counter/Timer is connected to the COM1 port using a standard serial cable with 9-pin DIN connectors on each end.

4. The Solomat MPM4000 Matrix Processor is connected to the COM2 port using the RS-232 interface cable that is included with the Solomat system hardware.

Radon Injector Interface

The radon injector interface is connected to the LPT2 parallel port of the Z248 computer using a standard Centronics parallel printer cable.

The interface controls the radon injector which is located in the radiochemistry laboratory and is connected through a 15-conductor telephone cable. The wires are color-coded and the connections to the interface are listed in table 6.

The voltages utilized by the interface are supplied by two power supplies. A Lambda model LK343FM voltage-selectable regulated power supply is used to provide 12 Vdc, and an Electro model EFB filtered DC power supply is adjusted to provide 7.5 Vdc.

FROM	TO
Red binding post	Lambda power supply, +12 Vdc
Black binding post	Lambda power supply, ground
Black binding post	Black/white stripe wire, injector cable
Relay 1, COM	Red binding post
Relay 1, NO	Relay 8, COM
Relay 2, COM	Red binding post
Relay 2, NO	Orange/black stripe, injector cable
Relay 3, COM	Electro power supply, +7.5 Vdc
Relay 3, COM	Relay 7, COM
Relay 3, NO	Red wire, injector cable
Relay 4, COM	Relay 5, COM
Relay 4, NO	Black wire, injector cable
Relay 5, COM	Electro power supply, ground
Relay 5, NO	Orange wire, injector cable
Relay 7, COM	Relay 3, COM
Relay 7, NO	Green wire, injector cable
Relay 8, COM	Relay 1, NO
Relay 8, NC	Green/black stripe wire, injector cable

Table 6. Radon Injector Interface Connections

Appendix B
Setting Up the PC

The radon control program (RCP) is designed to operate on an IBM or compatible PC running under DOS 3.3 or later, and having a BASIC interpreter equivalent to GW-BASIC 3.22. The program is written in BASIC and is a stand-alone program which automatically creates other necessary files in the directory in which the RCP resides. A subdirectory called RADON was set aside on the hard drive specifically to contain the RCP and associated files.

The system is configured to reboot itself in the event of a power failure. This is accomplished by editing the autoexec.bat file in the root directory of the hard drive and adding two lines to the end of file.

```
cd radon  
radon basic
```

The first line loads the screen-dump program into memory so that it will be available any time it is needed. The second line changes the working directory on the computer to the subdirectory in which the RADON.BAS program resides. The last line loads and runs the BASIC program, RADON.BAS.

In the event of a power failure, all the equipment will shut down. However, the Solomat MPM4000 will retain the program

that it contains. When the power is returned, the PC will begin its initialization sequence and the Solomat system, sensing this, will also turn itself on. When the PC executes the autoexec.bat file, the RCP will be reloaded and will begin to run. This initialization will be annotated in the LOG.DAT file, showing the time and date. It is very important to remember to not leave a disk in the floppy drive, or the system will try to boot from the floppy disk, and the automatic system reboot will fail.

Before the radon control program can be used, all the equipment must be configured as described in appendix A and turned on. Once accomplished, change the current directory to the RADON subdirectory by typing "CD RADON". Now invoke the BASIC interpreter by typing BASIC, load the RCP into memory, and type RUN.

Once running, the RCP will initialize the Ortec 996 counter/timer and take care of all the housekeeping required to manage all the equipment attached to the system. The program will automatically make an entry in the LOG.DAT file on the hard drive indicating the time that the system was initialized.

Appendix C

Radon Control Program Listing

```
1 'Radon Control Program..Version 1.0.    1 Feb 1991
  y Capt William R. Wharton, Jr.
2 .....
3 'This program is designed to automatically control the
  concentration of radon within a radon chamber, using a
  special interface and a radon injector.
4 'Utilities are also coded into the program which allow
  the user a number of functions which can be accessed
  while the program is running.
5 'Details of the theory and operation of this program can
  be found in the master's degree thesis,
6 'AN ENVIRONMENTALLY CONTROLLED CHAMBER FOR THE STUDY OF
  RADON DETECTION, a thesis written for the Air Force
  Institute of Technology,
7 'Wright-Patterson Air Force Base, OH.
8 '.....

10 OUT 632,0: 'Clear all interface channels.
20 DEFINT A: FALSE=0: TRUE=NOT FALSE: SPINCYCLE=FALSE:
LOWRDN=FALSE: LOWLEVEL=FALSE: DATAOK=FALSE: LOGFLAG=60:
AUTOINJECT=TRUE: 'Initialize flags.
30 DIM A(21254): 'Set up array for graphic storage.
40 COLOR 15: SCREEN 9,,1,1: CLS: KEY OFF: SCREEN 9,,0,0:
CLS: KEY OFF: 'Clear all screens.
50 BL1$=""                                ": 'Short erasure string.
60 BL2$=""                                ": 'Long erasure string (80
spaces).

70 '-----initialize 996 counter/Solomat-----
80 OPEN"com1:300,n,8,1" AS #1: 'COM1 1 will be used to
address the counter.
90 PRINT #1,"INIT": GOSUB 1830: 'Initialize the counter.
100 OPEN "log.dat" FOR APPEND AS #3: 'Prepare to annotate
LOG.DAT file.
110 PRINT #3,CHR$(13);"Initialized", DATE$, TIME$: CLOSE 3:
'Annotate initialization to LOG.DAT file.
120 PRINT #1,"START": GOSUB 1830: 'Instruct counter to begin
counting.
130 GOSUB 2320: 'Read Solomat to prevent zero initial
values.
```

```

140 '-----load graph array if present-----
150 ON ERROR GOTO 240: 'Trap error if file does not exist,
etc..
160 OPEN "graph.arr" FOR INPUT AS #3: 'Prepare to input
graphic array data.
170 LOCATE 3,1: PRINT BL2$: LOCATE 3,30: PRINT"STANDBY -
LOADING GRAPH"
180 INPUT #3,T$: INPUT #3,D$: GOSUB 3580: 'Calculate elapsed
time since graph data was written to file.
190 IF ET>=1440 THEN CLOSE 3: ON ERROR GOTO 0: GOTO 320: 'If
data is older than 24 hours, do not load data.
200 WHILE NOT EOF(3): 'Data is current. Execute this loop
while there is data still left to read in the file.
210 INPUT #3, XDATA, A(XDATA): GOTO 200: 'Get the data from
file and put into correct graphic array element.
220 WEND
230 ON ERROR GOTO 0: CLOSE 3: GOTO 250: 'Stop error
trapping, close files.
240 GET(68,76)-(546,244),A:CLOSE 3: CLS: RESUME 320: 'File
error. Load graphic array with blank screen, close file,
clear screen.
250 KLIKS=INT(ET/3): 'Calculate number of pixels to shift
graphic data.
260 SCREEN 9,,1,0: PUT(68,76),A: 'Put graphic array on
hidden screen.
270 SCREEN 9,,0,0: GET(69,76)-(546,244),A: SCREEN 9,,1,0:
'Erase graphic array by copying blank visible screen to
array.
280 GET(68+KLIKS+1,76)-(546,244),A: 'Write only current data
to graphic array.
290 LINE(68,76)-(546,244),0,BF: 'Erase the graph from the
hidden screen.
300 PUT(68,76),A: 'Write the current data to the hidden
screen.
310 SCREEN,,0,0: PUT(68,76),A: 'Write the current graph to
the visible screen.
320 LOCATE 3,1: PRINT BL2$: 'Erase standby message.
330 ON ERROR GOTO 0: 'Stop error trapping.

340 '-----load limits from disk-----
350 ON ERROR GOTO 390: 'Trap errors if file doesn't exist,
etc.
360 OPEN "limits.dat" FOR INPUT AS #3: 'Prepare to load
LIMITS.DAT file if it exists.
370 INPUT #3, RDNLL, RDNUL, TEMPLL, TEMPUL, HUMLL, HUMUL,
MMHGLL, MMHGUL: 'Load lower an upper limits for radon,
temperature, humidity, and pressure.
380 CLOSE 3: GOTO 400
390 RESUME 400: 'If error exists.

```



```

400 ON ERROR GOTO 0: 'Stop error trapping.
410 INITFLAG=1: 'Setting this flag indicates that sytem has
just initialized.

420 '-----initialize graphic screen-----
430 GOSUB 1170: 'Draw graphic template.
440 GOSUB 1520: 'Overlay the grid on the graph.
450 SCREEN ,,1,0: 'Address the hidden screen.
460 GOSUB 1170: 'Draw graphic template.
470 SCREEN ,,0,0: 'Address visual screen.
480 VIS=0: 'Initialize VIS variable as the visual screen
number.

490 '-----load repshots.dat-----
500 ON ERROR GOTO 540: 'Trap error if file doesn't exist,
etc.
510 OPEN "repshots.dat" FOR INPUT AS #3: 'Prepare to load
REPSHOTS.DAT file if it exists.
520 INPUT #3, REPSHOTS: 'Load the number of replacement
shots which need to be made at the end of the day.
530 CLOSE 3: GOTO 550
540 RESUME 550: 'If error exists.
550 ON ERROR GOTO 0: 'Stop error trapping.

560 '-----begin main loop-----
570 A$=TIME$: IF A$=OLDTIME$ THEN 570: 'Only update time
once per second.
580 LOCATE 20,63: PRINT A$: OLDTIME$=A$: 'Update present
time.
590 MINUTE$=MID$(A$,4,2): MINUTES=VAL(MINUTE$): 'Determine
minutes.
600 SEC$=RIGHT$(A$,2): 'Pick out seconds string.
610 IF RIGHT$(A$,2)="00" AND (MINUTES/3 = INT(MINUTES/3))
THEN GOSUB 2110: GOSUB 780: GOSUB 4000: IF REPFLAG=TRUE THEN
GOSUB 4420: 'At 3 minute intervals, cycle 996 counter,
update graphic screen, radon regulation, replacement shots.
620 IF SEC$="00" OR SEC$="20" OR SEC$="40" THEN GOSUB 2320:
GOSUB 2480: GOSUB 3500: 'At 20 second intervals, read
Solomat, update screen values, check for temperature,
humidity, pressure alarms
630 IF RIGHT$(A$,2)="00" AND (MINUTES-1)/12 =
INT((MINUTES-1)/12) THEN GOSUB 3930: 'At 12 minute
intervals, save graphic screen to disk.
640 IF A$="00:04:00" AND REPSHOTS>0 THEN REPFLAG=TRUE:
'Perform reservoir replacements if needed.
650 IF A$="01:15:00" OR A$="01:18:00" THEN FOR XX=1 TO 10:
GOSUB 2550: FOR YY=1 TO 1000: NEXT YY: NEXT XX: 'Cycle
syringe to flush chamber air from injector.
660 A$=INKEY$: 'Look for pressed key.
670 IF A$="u" OR A$="U" THEN GOSUB 4540: 'Toggle autoinject

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option.
680 IF A$="v" OR A$="V" THEN GOSUB 4570: 'Toggle print
variable option on/off.
690 IF A$="q" OR A$="Q" THEN CLOSE: SCREEN 0,0,0: STOP:
'Quit program.
700 IF A$="d" OR A$="D" THEN GOSUB 1870: 'Select disk
functions.
710 IF A$="i" OR A$="I" THEN NBRINJ=1: GOSUB 1580: NBRINJ=0:
'Perform injection.
720 IF A$="r" OR A$="R" THEN NBRREP=1: GOSUB 1750:
REPSHOTS=REPSHOTS-1: GOSUB 4440: NBRREP=0: 'Perform
replacement, annotate LOG.DAT file.
730 IF A$="c" OR A$="C" THEN GOSUB 2550: 'Cycle syringe.
740 IF A$="f" OR A$="F" THEN GOSUB 2610: 'Manual interface
control.
750 IF A$="a" OR A$="A" THEN GOSUB 2750: 'Select alarms
submenu.
760 IF A$="l" OR A$="L" THEN GOSUB 2720: 'Toggle log
interval.
770 GOTO 570: 'Repeat main loop.

780 'SUBROUTINE:---UPDATE GRAPHIC SCREEN---
790 IF INITFLAG=1 THEN 840: 'If program has just
initialized, don't try to update graphic screen.
800 IF VIS=1 THEN ACT=0 ELSE ACT=1: 'Determine which screen
is active.
810 SCREEN , ,ACT,VIS: 'Begin working on hidden screen.
820 LINE (68,76)-(546,244),0,BF: 'Erase the graphic area.
830 PUT (68,76),A: 'Put the graphic array data on hidden
screen, shifted one pixel left.
840 NEWTEMP=INT(245-4.25*TEMP): 'Calculate the graphic y
value for temperature.
850 IF NEWTEMP>245 THEN NEWTEMP=245 ELSE IF NEWTEMP<76 THEN
NEWTEMP=76: 'Keep data within the graphic area.
860 NEWHUM=INT(245-1.7*HUM): 'Calculate graphic y value for
humidity.
870 IF NEWHUM>245 THEN NEWHUM=245 ELSE IF NEWHUM<76 THEN
NEWHUM=76: 'Keep data within the graphic area.
880 NEWMMHG=INT(1435-1.7*MMHG): 'Calculate graphic y value
for pressure.
890 IF NEWMMHG>245 THEN NEWMMHG=245 ELSE IF NEWMMHG<76 THEN
NEWMMHG=76: 'Keep data within the graphic area.
900 NEWRDN=INT(245-1.0625*RDN): 'Calculate graphic y value
for radon.
910 IF NEWRDN>245 THEN NEWRDN=245 ELSE IF NEWRDN<76 THEN
NEWRDN=76: 'Keep data within the graphic area.
920 IF INITFLAG=1 THEN 990: 'Don't try to draw graph if
system has just been initialized.
930 COLOR 12: LINE(545,OLDTEMP)-(546,NEWTEMP): 'Draw line
from last temperature to new one.

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940 COLOR 14: LINE(545,OLDHUM)-(546,NEWHUM): 'Draw line from
last humidity to new one.
950 COLOR 11: LINE(545,OLDMMHG)-(546,NEWMMHG): 'Draw line
from last pressure to new one.
960 IF INITRN=0 THEN PSET (546,NEWRDN): GOTO 990: 'If radon
concentration has only been calculated once, just set point.
970 COLOR 10: LINE(545,OLDRDN)-(546,NEWRDN): 'If radon has
been calculated previously, draw line from old concentration
to new.
980 IF INJFLAG=1 THEN COLOR 13:
LINE(546,NEWRDN-5)-(546,NEWRDN+20): INJFLAG=0: 'If injection
has been performed this cycle, draw vertical line on graph.
990 OLDTEMP=NEWTEMP: 'Store temperature until next cycle.
1000 OLDHUM=NEWHUM: 'Store humidity until next cycle.
1010 OLDMMHG=NEWMMHG: 'Store pressure until next cycle.
1020 OLDRDN=NEWRDN: 'Store radon until next cycle.
1030 GOSUB 2480: 'Update the parameter values on screen.
1040 IF INITFLAG=1 THEN INITFLAG=0: GOTO 1140: 'Don't try to
update screen if system has just been initialized.
1050 GET (69,76)-(546,244),A: 'Dump graph to array.
1060 GOSUB 1520: 'Overlay the grid on the graph.
1070 GOSUB 3500: GOSUB 3550: 'Check for alarms.
1080 LOCATE 19,63: PRINT OLDTIME$: 'Print time that this
cycle stopped.
1090 LOCATE 1,61: IF LOGFLAG=3 THEN PRINT"3 ";; ELSE
PRINT"60";: 'Ensure log interval indicator is correct on
this screen.
1100 LOCATE 25,77: IF AUTOINJECT=TRUE THEN PRINT" ON";: ELSE
PRINT"OFF";: 'Ensure autoinject indicator is correct on this
screen.
1110 IF VIS=1 THEN VIS=0 ELSE VIS=1: 'Initialize VIS
variable for visible screen number.
1120 SCREEN ,,ACT,VIS: 'Flip hidden screen to visible
screen.
1130 IF INITRN=0 THEN INITRN=1: 'Radon has been calculated,
set flag.
1140 LOCATE 25,19: PRINT COUNTS;; LOCATE 20,7: PRINT
DATE$;; 'Update screen.
1150 IF INITRN=1 THEN LOCATE 23,61: COLOR 10: PRINT RDN;
"pCi/l ": COLOR 15: 'Print radon concentration if RNFLAG is
set.
1160 RETURN

1170 'SUBROUTINE:---DRAW GRAPH TEMPLATE---
1180 PSET (67,75): DRAW "r480 d170 1480 u170": 'Draw box
around graphic area.
1190 LOCATE 5,20: PRINT"RADON ENVIRONMENTAL CONTROL
PARAMETERS"
1200 COLOR 12: LOCATE 22,4: PRINT"TEMPERATURE";: COLOR 14:
PRINT"      RELATIVE HUMIDITY";

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1210 COLOR 11: PRINT"      PRESSURE";: COLOR 10: PRINT"
RADON CONCENTRATION"
1220 COLOR 12: LOCATE 4,1: PRINT"TEMP"
1230 LOCATE 4,6: COLOR 14: PRINT"REL": LOCATE 5,6:
PRINT"HUM"
1240 COLOR 11: LOCATE 4,69: PRINT"PRES": COLOR 10: LOCATE
4,75: PRINT"RADON": LOCATE 5,75: PRINT"CONC"
1250 COLOR 12: LOCATE 6,1: PRINT"40": LOCATE 9,1: PRINT"30"
1260 LOCATE 12,1: PRINT"20": LOCATE 15,1: PRINT"10": LOCATE
18,2: PRINT"0"
1270 COLOR 14: LOCATE 6,6: PRINT"100": LOCATE 9,7: PRINT"75"
1280 LOCATE 12,7: PRINT"50": LOCATE 15,7: PRINT"25": LOCATE
18,8: PRINT"0"
1290 COLOR 11: LOCATE 6,70: PRINT"800": LOCATE 9,70:
PRINT"775"
1300 LOCATE 12,70: PRINT"750": LOCATE 15,70: PRINT"725":
LOCATE 18,70: PRINT"700"
1310 COLOR 10: LOCATE 6,76: PRINT"160": LOCATE 9,76:
PRINT"120"
1320 LOCATE 12,77: PRINT"80": LOCATE 15,77: PRINT"40":
LOCATE 18,78: PRINT"0"
1330 COLOR 7
1340 LOCATE 1,1: PRINT"A";: COLOR 11: PRINT"U";: COLOR 7:
PRINT"to"
1350 LOCATE 1,6: COLOR 11: PRINT"V";: COLOR 7: PRINT"ars";
1360 LOCATE 1,11: COLOR 11: PRINT"D";: COLOR 7: PRINT"isk
Fcns";
1370 LOCATE 1,21: COLOR 11: PRINT"I";: COLOR 7:
PRINT"nject";
1380 LOCATE 1,27: PRINT"/";: COLOR 11: PRINT"R";: COLOR 7:
PRINT"eplace";
1390 LOCATE 1,36: COLOR 11: PRINT"C";: COLOR 7: PRINT"ycle
Syringe";
1400 LOCATE 1,50: COLOR 11: PRINT"A";: COLOR 7:
PRINT"larms";
1410 LOCATE 1,57: COLOR 11: PRINT"L";: COLOR 7: PRINT"og:";:
COLOR 15: PRINT"60";: COLOR 7
1420 LOCATE 1,64: PRINT"Inter";: COLOR 11: PRINT"F";: COLOR
7: PRINT"ace";
1430 LOCATE 1,77: COLOR 11: PRINT"Q";: COLOR 7: PRINT"uit";:
COLOR 15
1440 COLOR 11: LINE (1,20)-(635,20): LINE(1,285)-(635,285):
LINE(1,327)-(635,327)
1450 LINE(1,285)-(1,327): LINE(135,285)-(135,327):
LINE(320,285)-(320,327): LINE(431,285)-(431,327):
LINE(635,285)-(635,327): COLOR 15
1460 LOCATE 19,6: PRINT"-24 hrs      -18 hrs      -12
hrs      -6 hrs"
1470 LOCATE 20,1: PRINT"DATE: ": LOCATE 20,34: PRINT"TIME
(hours)"

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1480 LOCATE 19,72: PRINT"-Updated": LOCATE 20,72:
PRINT"-Current"
1490 LOCATE 25,1: PRINT"Counts last cycle:";
1500 LOCATE 25,30: PRINT"Alarms:";
1510 LOCATE 25,65: PRINT"Autoinject:  ON";

1520 'SUBROUTINE:---OVERLAY GRID ON GRAPH---
1530 COLOR 15: LINE (187,75)-(187,245),,,&HAAAA: LINE
(307,75)-(307,245),,,&HAAAA
1540 LINE (427,75)-(427,245),,,&HAAAA
1550 COLOR 15: LINE (67,118)-(547,118),,,&HAAAA: LINE
(67,160)-(547,160),,,&HAAAA
1560 LINE (67,202)-(547,202),,,&HAAAA
1570 RETURN

1580 'SUBROUTINE:---INJECT RADON---
1590 GOSUB 2550: 'Prime valve 1 plenum.
1600 FOR C=1 TO NBRINJ: 'Do NBRINJ injections.
1610 OUT 632,1: FOR X=0 TO 800: NEXT X: 'Open valve 1.
1620 OUT 632,81: FOR X=0 TO 10000: NEXT X: 'Draw syringe.
1630 OUT 632,0: FOR X=0 TO 800: NEXT X: 'Close valve 1.
1640 OUT 632,2: FOR X=0 TO 800: NEXT X: 'Open valve 2.
1650 OUT 632,14: FOR X=0 TO 10000: NEXT X: 'Push syringe.
1660 OUT 632,0: 'Close valve 2.
1670 INJFLAG=1: 'Set flag to signal injection hs occurred.
1680 OPEN "log.dat" FOR APPEND AS #3: 'Prepare to annotate
LOG.DAT file.
1690 PRINT #3,"Injection accomplished at "; TIME$; " on ";
DATE$: CLOSE 3: 'Annotate LOG.DAT file.
1700 REPSHOTS=REPSHOTS+1: 'Increment number of replacement
shots to make.
1710 OPEN "repshots.dat" FOR OUTPUT AS #3: 'Prepare to
update REPSHOTS.DAT file.
1720 PRINT #3, REPSHOTS: CLOSE 3: 'Update REPSHOTS.DAT file
with new repshots number.
1730 NEXT C
1740 RETURN

1750 'SUBROUTINE:---REPLACE RADON---
1760 FOR C=1 TO NBRREP: 'Perform NBRREP replacement shots.
1770 OUT 632,82: FOR X=0 TO 8000: NEXT X: 'Draw syringe with
valve 2 open.
1780 OUT 632,0: FOR X=0 TO 800: NEXT X: 'Close valve 2.
1790 OUT 632,13: FOR X=0 TO 8000: NEXT X: 'Push syringe with
valve 1 open.
1800 OUT 632,0: 'Close valve 1.
1810 NEXT C
1820 RETURN

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1830 'SUBROUTINE:---CHECK COUNTER REPLY STATUS---
1840 INPUT #1, RESP$: 'Get status string from counter.
1850 IF (RESP$<>"%000000069") AND (LEFT$(RESP$,4)<>"%001")
THEN PRINT RESP$: CLOSE 1: CLOSE 2: STOP: 'Stop on all but
code 69 or initialization code.
1860 RETURN

1870 'SUBROUTINE:---DISK FUNCTIONS---
1880 LOCATE 3,5: COLOR 15: PRINT"P";: COLOR 11: PRINT"rint
log file"
1890 LOCATE 3,24: COLOR 15: PRINT"T";: COLOR 11:
PRINT"ransfer log to floppy"
1900 LOCATE 3,50: COLOR 15: PRINT"R";: COLOR 11: PRINT"eset
log file"
1910 LOCATE 3,70: PRINT "E";: COLOR 15: PRINT"X";: COLOR 11:
PRINT"it": COLOR 15
1920 A$=INKEY$: IF A$="" THEN 1920: 'Wait for depressed key.
1930 IF A$="p" OR A$="P" THEN 2010
1940 IF A$="t" OR A$="T" THEN 2060
1950 IF A$="r" OR A$="R" THEN 1970
1960 IF A$="x" OR A$="X" THEN 2000 ELSE 1920
1970 KILL "log.dat"
1980 OPEN"log.dat" FOR APPEND AS #3: 'Prepare to annotate
LOG.DAT file.
1990 PRINT #3,"File reinitialized at "; TIME$; " on ";
DATE$: CLOSE 3: 'Annotate LOG.DAT file.
2000 LOCATE 3,1: PRINT BL2$: A$="": RETURN: 'Erase sub menu.
2010 OPEN "log.dat" FOR INPUT AS #3: 'Prepare to load
LOG.DAT for printing.
2020 IF EOF(3) THEN CLOSE 3: GOTO 2000: 'Stop when all data
has been printed.
2030 INPUT #3,D1$: 'Get line of data from log file.
2040 LPRINT D1$: 'Print the data.
2050 GOTO 2020: 'Repeat until all data is printed.
2060 LOCATE 3,1: PRINT BL2$: LOCATE 3,1: INPUT"Enter file
name (Null ENTER to exit)"; F$: 'Get filename to write to
floppy disk.
2070 IF F$="" THEN GOTO 2000 ELSE OPEN "A:"+F$ FOR OUTPUT AS
#2: 'Exit if null string, else open file to floppy.
2080 OPEN "log.dat" FOR INPUT AS #3: 'Open LOG.DAT from
which to read.
2090 IF EOF(3) THEN CLOSE 3: CLOSE 2: GOTO 2000: 'Stop when
all data is read.
2100 INPUT #3, XFER$: PRINT #2, XFER$: GOTO 2090: 'Get data
from hard drive, write to floppy.

2110 'SUBROUTINE:---CYCLE COUNTER & AVERAGE TEMP, HUM,
MMHG---
2120 PRINT #1,"STOP": GOSUB 1830: 'Stop counter, check
status.

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2130 PRINT #1,"SHOW_COUNTS": INPUT #1,COUNT$: GOSUB 1830:
'Get count$ from counter, check status.
2140 PRINT #1,"CLEAR_COUNTER": GOSUB 1830: 'Reset counter,
check status.
2150 PRINT #1,"START": GOSUB 1830: 'Restart counter.
2160 COUNTS=VAL(COUNT$): TOTCTS=TOTCTS+COUNTS: 'Get counts,
sum counts for this hour.
2170 RDN=(COUNTS*.001246*20): 'Calculate radon concentration
for this 3-minute interval.
2180 RDN=INT(RDN*10)/10: 'Truncate radon concentration to 1
decimal place.
2190 IF PASSES=0 THEN 2240
2200 TEMP=SUMTEMP/PASSES: SUMTEMP=0: 'Average temperature by
dividing by number of passes completed in this 3-minute
interval.
2210 HUM=SUMHUM/PASSES: SUMHUM=0: 'Average humidity by
dividing by number of passes completed in this 3-minute
interval.
2220 MMHG=SUMMMHG/PASSES: SUMMMHG=0: 'Average pressure by
dividing by number of passes completed in this 3-minute
interval.
2230 PASSES=0: 'Restart averaging for new 3-minute interval.
2240 IF LOGFLAG<>3 THEN 2250 ELSE OPEN "log.dat" FOR APPEND
AS #3: PRINT #3, DATE$; " "; LEFT$(OLDTIME$,5)+"/3";
TAB(23); COUNTS; TAB(31); RDN; TAB(40); TEMP; TAB(52); HUM;
TAB(65); MMHG: CLOSE 3: 'If log option is set at 3 minutes,
log information.
2250 IF MID$(A$,4,2)="00" AND RIGHT$(A$,2)="00" THEN 2260
ELSE 2310: 'If time is exactly on the hour, write hourly
information to LOG.DAT file.
2260 OPEN "log.dat" FOR APPEND AS #3
2270 PRINT#3, DATE$; " "; LEFT$(OLDTIME$,5)+"/60"; TAB(23);
TOTCTS; TAB(31); INT(TOTCTS*.001246*10)/10; TAB(40); TEMP;
TAB(52); HUM; TAB(65); MMHG: CLOSE 3
2280 IF THISFLAG=0 THEN THISFLAG=1: GOTO 2300: 'Check for
slow cycle injection only after the first incomplete hourly
measurement cycle.
2290 IF (TOTCTS<94960!) AND (LOWRDN=FALSE) AND
(SPINCYCLE=FALSE) AND (AUTOINJECT=TRUE) THEN NBRINJ=3: GOSUB
1580: NBRINJ=0: 'If average counts falls below 94960, then
perform 1 injection.
2300 TOTCTS=0: 'Clear hourly count sum for next hour
interval.
2310 RETURN

2320 'SUBROUTINE:---READ SOLOMAT CHANNELS---
2330 OPEN"com2:9600,n,8,1,ds1000" AS #2: 'Open channel to
read Solomat.
2340 TALLY=0: 'There are 3 Solomat channels to read. Set
counter at 0.

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2350 WHILE LOC(2)>0: 'Loop while there is data.
2360 INPUT #2,B$: INFO$=RIGHT$(B$,16): GOTO 2380: 'Get the
data. Keep only the right 16 characters.
2370 WEND: GOTO 2350
2380 IF RIGHT$(INFO$,1)="1" THEN TEMP=VAL(LEFT$(INFO$,6)):
TALLY=TALLY+1: 'Channel read was temperature. Take data out
of string.
2390 IF RIGHT$(INFO$,1)="2" THEN HUM=VAL(LEFT$(INFO$,6)):
TALLY=TALLY+1: 'Channel read was humidity. Take data out of
string.
2400 IF RIGHT$(INFO$,1)="3" THEN MMHG=VAL(LEFT$(INFO$,6)):
TALLY=TALLY+1: 'Channel read was pressure. Take data out of
string.
2410 IF TALLY <> 3 THEN 2350: 'If all 3 channels haven't
been read, repeat.
2420 CLOSE 2: 'Close file 2.
2430 SUMTEMP=SUMTEMP+TEMP: 'Sum temperatures for average at
end of 3-minute interval.
2440 SUMHUM=SUMHUM+HUM: 'Sum humidity for average at end of
3-minute interval.
2450 SUMMMHG=SUMMMHG+MMHG: 'Sum pressure for average at end
of 3-minute interval.
2460 PASSES=PASSES+1: 'Increment passes by 1.
2470 RETURN

2480 'SUBROUTINE:---UPDATE PARAMETER VALUES ON SCREEN---
2490 MMHG=INT(MMHG): 'Truncate pressure.
2500 LOCATE 23,4: COLOR 12: PRINT USING "##.##"; TEMP;;
PRINT" Deg C.  "
2510 LOCATE 23,24: COLOR 14: PRINT USING "##.##"; HUM;;
PRINT"% RH  "
2520 LOCATE 23,43: COLOR 11: PRINT MMHG; "mmHg  ": COLOR 15
2530 LOCATE 3,1: IF VARS=TRUE THEN PRINT LOWRDN; LOWLEVEL;
LOWPASS; DEFINJ; SPINCYLE; SPINMINUTES; "      " ELSE PRINT
BL2$: 'Print injector variables or erase according to flag.
2540 RETURN

2550 'SUBROUTINE:---CYCLE SYRINGE---
2560 OUT 632,1: FOR X=1 TO 800: NEXT X: 'Open valve 1.
2570 OUT 632,81: FOR X=0 TO 5000: NEXT X: 'Draw syringe with
valve 1 open.
2580 OUT 632,13: FOR X=0 TO 5000: NEXT X: 'Push syringe with
valve 1 open.
2590 OUT 632,0: 'Cancel all interface commands.
2600 RETURN

2610 'SUBROUTINE:---MANUAL INJECTOR CONTROL---
2620 CODECHK$=""
2630 LOCATE 3,27: INPUT"Enter interface code: "; CODE$
2640 IF CODE$="" THEN LOCATE 3,27: PRINT BL1$;; PRINT BL1$:

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RETURN: 'if no code entered, cancel function.
2650 FOR X=1 TO LEN(CODE$): IF ASC(MID$(CODE$,X,1))<48 OR
ASC(MID$(CODE$,X,1))>57 THEN CODECHK$="bad": 'Ensure all
characters in code are numerals.
2660 NEXT X
2670 IF VAL(CODE$)=92 OR VAL(CODE$)=20 OR VAL(CODE$)=72 THEN
CODECHK$="bad"
2680 IF CODECHK$="bad" THEN LOCATE 3,48: BEEP: PRINT BL1$;:
GOTO 2610: 'If an unacceptable code is entered, cancel it,
return for another code.
2690 LOCATE 3,48: PRINT BL1$;: 'If code was valid, erase the
code from the display.
2700 OUT 632,VAL(CODE$): 'Send the code to LPT2.
2710 GOTO 2610: 'Repeat subroutine.

2720 'SUBROUTINE:---TOGGLE LOG INTERVAL---
2730 IF LOGFLAG=3 THEN LOGFLAG=60: LOCATE 1,61: PRINT"60":
RETURN: 'Toggle log interval, write to screen.
2740 IF LOGFLAG=60 THEN LOGFLAG=3: LOCATE 1,61: PRINT"3 ":
RETURN: 'Toggle log interval update to screen.

2750 'SUBROUTINE:---SET ALARM LIMITS---
2760 LOCATE 3,1: PRINT BL2$
2770 LOCATE 3,1: COLOR 15: PRINT"R";: COLOR 11: PRINT"adon
Concentration"
2780 LOCATE 3,23: COLOR 15: PRINT"T";: COLOR 11:
PRINT"emperature"
2790 LOCATE 3,37: COLOR 15: PRINT"H";: COLOR 11:
PRINT"umidity"
2800 LOCATE 3,48: COLOR 15: PRINT"P";: COLOR 11:
PRINT"ressure"
2810 LOCATE 3,59: COLOR 15: PRINT"C";: COLOR 11: PRINT"lear
Alarm"
2820 LOCATE 3,74: PRINT"E"; :COLOR 15: PRINT"X";: COLOR 11:
PRINT"it";: COLOR 15
2830 A$=INKEY$: IF A$="" THEN 2830: 'Wait for keypress.
2840 IF A$="r" OR A$="R" THEN 2940
2850 IF A$="t" OR A$="T" THEN 3040
2860 IF A$="h" OR A$="H" THEN 3140
2870 IF A$="p" OR A$="P" THEN 3240
2880 IF A$="c" OR A$="C" THEN GOSUB 3440: GOTO 2900: 'Clear
screen, return to main menu.
2890 IF A$<>"x" AND A$<>"X" THEN 2830: 'No valid option was
selected, so repeat.
2900 LOCATE 3,1: PRINT BL2$: 'Erase submenu line.
2910 OPEN "limits.dat" FOR OUTPUT AS #3: 'Prepare to write
limit to disk.
2920 PRINT #3, RDNLL, RDNUL, TEMPLL, TEMPUL, HUMLL, HUMUL,

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MMHGLL, MMHGUL: 'Write low and high level for radon,
temperature, humidity, and pressure.

2930 CLOSE 3: RETURN

2940 'SUBROUTINE:---SET RADON CONCENTRATION LIMITS---

2950 GOSUB 3340: 'Get input from user.

2960 IF OPT\$="look" THEN 2990: 'Look at current radon alarm
settings.

2970 IF OPT\$="change" THEN 3010: 'Change radon alarm
settings.

2980 IF OPT\$="exit" THEN 2750: 'Return to alarm submenu.

2990 PRINT"Radon: Lower limit = "; RDNLL; " Upper limit =
"; RDNUL;: LOCATE 3,65: COLOR 15: PRINT"<Press ENTER>"

3000 A\$=INKEY\$: IF A\$="" THEN 3000 ELSE OPT\$="exit": GOTO

2980: 'Wait for keypress then return to alarm submenu.

3010 INPUT"Enter lower limit"; RDNLL

3020 LOCATE 3,1: PRINT BL2\$: LOCATE 3,1: INPUT"Enter upper
limit"; RDNUL

3030 OPT\$="exit": GOTO 2970: 'Return to alarm submenu after
entering new limits.

3040 'SUBROUTINE:---SET TEMPERATURE LIMITS---

3050 GOSUB 3340: 'Get input from user.

3060 IF OPT\$="look" THEN 3090: 'Look at current temperature
alarm settings.

3070 IF OPT\$="change" THEN 3110: 'Change temperature alarm
settings.

3080 IF OPT\$="exit" THEN 2750: 'Return to alarm submenu.

3090 PRINT"Temperature: Lower limit = "; TEMPLL; " Upper
limit = "; TEMPUL;: LOCATE 3,65: COLOR 15: PRINT"<Press
ENTER>"

3100 A\$=INKEY\$: IF A\$="" THEN 3100 ELSE OPT\$="exit": GOTO

3080: 'Wait for keypress then return to alarm submenu.

3110 INPUT"Enter lower limit"; TEMPLL

3120 LOCATE 3,1: PRINT BL2\$: LOCATE 3,1: INPUT"Enter upper
limit"; TEMPUL

3130 OPT\$="exit": GOTO 3080: 'Return to alarm submenu after
entering new limits.

3140 'SUBROUTINE:---SET HUMIDITY LIMITS---

3150 GOSUB 3340: 'Get input from user.

3160 IF OPT\$="look" THEN 3190: 'Look at current humidity
alarm settings.

3170 IF OPT\$="change" THEN 3210: 'Change humidity alarm
settings.

3180 IF OPT\$="exit" THEN 2750: 'Return to alarm submenu.

3190 PRINT"Humidity: Lower limit = "; HUMLL; " Upper
limit = "; HUMUL;: LOCATE 3,65: COLOR 15: PRINT"<Press
ENTER>"

3200 A\$=INKEY\$: IF A\$="" THEN 3200 ELSE OPT\$="exit": GOTO

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3180: 'Wait for keypress then return to alarm submenu.
3210 INPUT"Enter lower limit"; HUMLL
3220 LOCATE 3,1: PRINT BL2$: LOCATE 3,1: INPUT"Enter upper
limit"; HUMUL
3230 OPT$="exit": GOTO 3180: 'Return to alarm submenu after
entering new limits.

3240 'SUBROUTINE:---SET PRESSURE LIMITS---
3250 GOSUB 3340: 'Get input from user.
3260 IF OPT$="look" THEN 3290: 'Look at current pressure
alarm settings.
3270 IF OPT$="change" THEN 3310: 'Change pressure alarm
settings.
3280 IF OPT$="exit" THEN 2750: 'Return to alarm submenu.
3290 PRINT"Pressure: Lower limit = ";MMHGLL;"    Upper limit
= "; MMHGUL;; LOCATE 3,65: COLOR 15: PRINT"<Press ENTER>"
3300 A$=INKEY$: IF A$="" THEN 3300 ELSE OPT$="exit": GOTO
3280: 'Wait for keypress then return to alarm submenu.
3310 INPUT"Enter lower limit"; MMHGLL
3320 LOCATE 3,1: PRINT BL2$: LOCATE 3,1: INPUT"Enter upper
limit"; MMHGUL
3330 OPT$="exit": GOTO 3280: 'Return to alarm submenu after
entering new limits.

3340 'SUBROUTINE:---GET INPUT FROM USER---
3350 LOCATE 3,1: PRINT BL2$: LOCATE 3,1: 'Erase submenu
line.
3360 LOCATE 3,1: COLOR 15: PRINT"L";: COLOR 11: PRINT"ook at
current settings": 'Show options.
3370 LOCATE 3,43: COLOR 15: PRINT"C";: COLOR 11: PRINT"hange
alarm limits": COLOR 15
3380 A$=INKEY$: IF A$="" THEN 3380: 'Wait for keypress.
3390 IF A$="l" OR A$="L" THEN OPT$="look": GOTO 3420
3400 IF A$="c" OR A$="C" THEN OPT$="change": GOTO 3420
3410 IF A$="x" OR A$="X" THEN OPT$="exit": GOTO 3420
3420 LOCATE 3,1: PRINT BL2$: LOCATE 3,1: 'Erase submenu
line.
3430 RETURN

3440 'SUBROUTINE:---CLEAR ALARMS---
3450 LOCATE 25,38: FOR X=38 TO 64: PRINT CHR$(32);: NEXT X:
'Print spaces across alarm area.
3460 IF ACT=1 THEN ACT=0 ELSE IF ACT=0 THEN ACT=1:
'Determine which screen is hidden.
3470 SCREEN 9,,ACT,VIS: LOCATE 25,38: FOR X=38 TO 64: PRINT
CHR$(32);: NEXT X: 'Print spaces across alarm area on hidden
screen.
3480 IF ACT=1 THEN ACT=0 ELSE IF ACT=0 THEN ACT=1:

```

```

'Determine current active screen.
3490 SCREEN 9,,ACT,VIS: RETURN: "Change active screen back
to visible screen.

3500 'SUBROUTINE:---CHECK FOR TEMP/HUM/PRESS ALARMS---
3510 IF TEMP<TEMPLL OR TEMP>TEMPUL THEN LOCATE 25,38: COLOR
12: PRINT"TEMP";: COLOR 15: 'If temperature is out of
limits, turn on temperature alarm.
3520 IF HUM<HUMLL OR HUM>HUMUL THEN LOCATE 25,43: COLOR 14:
PRINT"HUM";: COLOR 15: 'If humidity is out of limits, turn
on humidity alarm.
3530 IF MMHG<MMHGLL OR MMHG>MMHGUL THEN LOCATE 25,47: COLOR
11: PRINT"MMHG";: COLOR 15: 'If pressure is out of limits,
turn on pressure alarm.
3540 RETURN

3550 'SUBROUTINE:---CHECK FOR RADON ALARM---
3560 IF RDN<RDNLL OR RDN>RDNUL THEN LOCATE 25,53: COLOR 10:
PRINT"RADON";: COLOR 15: 'If radon concentration is out of
limits, turn on radon alarm.
3570 RETURN

3580 'SUBROUTINE:---CALCULATE ELAPSED MINUTES SINCE GRAPH
DUMPED---
3590 '-----get time & date info for present time
3600 MO(2)=VAL(LEFT$(DATE$,2)): DA(2)=VAL(MID$(DATE$,4,2)):
YR(2)=VAL(RIGHT$(DATE$,2)): 'Extract month, day, and year
from date$.
3610 HR(2)=VAL(LEFT$(TIME$,2)): MN(2)=VAL(MID$(TIME$,4,2)):
SC(2)=VAL(RIGHT$(TIME$,2)): 'Extract hours, minutes, and
seconds from time$.
3620 '-----get time & date info for time that graph was
saved
3630 MO(1)=VAL(LEFT$(D$,2)): DA(1)=VAL(MID$(D$,4,2)):
YR(1)=VAL(RIGHT$(D$,2)): 'Extract month, day, and year from
D$.
3640 HR(1)=VAL(LEFT$(T$,2)): MN(1)=VAL(MID$(T$,4,2)):
SC(1)=VAL(RIGHT$(T$,2)): 'Extract hours, minutes, and
seconds from T$.
3650 FOR X=1 TO 2: 'Need to calculate elapsed time from base
time until present time and graph save time.
3660 Y=90: ED=0: 'Time base is 1990, set elapsed days=0.
3670 '-----calculate days in whole years since time base
year
3680 IF Y=YR(X) THEN 3740: 'If year in date being calculated
is 1990, skip to month calculation.
3690 IF INT(Y/4)=Y/4 THEN ED=ED+366: 'If the year is a leap
year, add 366 days to elapsed days.
3700 IF INT(Y/4)<>Y/4 THEN ED=ED+365: 'If the year is not a
leap year, add 365 days to elapsed days.

```

```

3710 Y=Y+1: 'Increment years.
3720 IF Y<>YR(X) THEN 3690: 'If years <> to the year in the
date being calculated, go back through whole year
calculations again.
3730 '-----calculate days in whole months in the last year
3740 IF MO(X)=1 THEN 3880: 'If month in date being
calculated is January, skip to days calculation.
3750 ED=ED+31: IF MO(X)=2 THEN 3880: 'Add 31 days for
January. If month in date being calculated is February, skip
to days calculation.
3760 IF INT(YR(X)/4)=YR(X)/4 THEN ED=ED+29 ELSE ED=ED+28:
'Add appropriate days for February.
3770 IF MO(X)=3 THEN 3880: 'If month in date being
calculated is March, skip to days calculation.
3780 ED=ED+31: IF MO(X)=4 THEN 3880: 'Add 31 days for March.
If month in date being calculated is April, skip to days
calculation.
3790 ED=ED+30: IF MO(X)=5 THEN 3880: 'Add 30 days for April.
If month in date being calculated is May, skip to days
calculation.
3800 ED=ED+31: IF MO(X)=6 THEN 3880: 'Add 31 days for May.
If month in date being calculated is June, skip to days
calculation.
3810 ED=ED+30: IF MO(X)=7 THEN 3880: 'Add 30 days for June.
If month in date being calculated is July, skip to days
calculation.
3820 ED=ED+31: IF MO(X)=8 THEN 3880: 'Add 31 days for July.
If month in date being calculated is August, skip to days
calculation.
3830 ED=ED+31: IF MO(X)=9 THEN 3880: 'Add 31 days for
August. If month in date being calculated is September, skip
to days calculation.
3840 ED=ED+30: IF MO(X)=10 THEN 3880: 'Add 30 days for
September. If month in date being calculated is October,
skip to days calculation.
3850 ED=ED+31: IF MO(X)=11 THEN 3880: 'Add 31 days for
October. If month in date being calculated is November, then
skip to days calculation.
3860 ED=ED+30: 'Add 30 days for November.
3870 '-----calculate elapsed minutes since time base
3880 ED=ED+DA(X): 'Add days in month being calculated to
elapsed days.
3890 ED=ED+(HR(X)/24)+MN(X)/(1440)+SC(X)/(86400!): 'Add to
elapsed days the fractional amounts from hours, minutes, and
seconds.
3900 EM=ED*1440: T(X)=EM: 'Convert elapsed days to minutes.
3910 NEXT X: ET=T(2)-T(1): 'Calculate elapsed time (minutes)
between present time and time the graph was stored.
3920 RETURN

```

```

3930 'SUBROUTINE:---SAVE BACKUP GRAPH---
3940 OPEN "graph.arr" FOR OUTPUT AS #3: 'Open the file to
save to disk.
3950 PRINT #3,TIME$: PRINT#3,DATE$: 'Save the time and date
of the graph save.
3960 FOR X=0 TO 21254: 'Loop through each graphic array
element.
3970 IF A(X)<>0 THEN PRINT #3,X,A(X): 'Only save non-zero
data. Save array index along with the data.
3980 NEXT X
3990 CLOSE 3: RETURN

4000 'SUBROUTINE:---RADON REGULATION---
4010 IF FIRSTFLAG=0 THEN FIRSTFLAG=1: RETURN: 'Do not allow
this subroutine on first pass. Radon concentration is
invalid on first pass due to incomplete cycle.
4020 IF LOWRDN=TRUE OR SPINCYLE=TRUE THEN GOSUB 4300: 'Save
all injector variables to disk for power loss possibility.
4030 IF DATAOK=FALSE THEN GOSUB 4340: 'If power loss did
occur, then reload injector variables from disk.
4040 IF AUTOINJECT=FALSE AND SPINCYLE=FALSE THEN RETURN:
'If autoinject is turned off and spincycle is not running,
then do not execute this subroutine.
4050 IF DEFINJ>0 THEN 4280: 'If calculated injections still
need to be performed, then go to that routine.
4060 IF SPINCYLE=FALSE THEN 4100: 'If spincycle is not
running, go into normal level checking mode.
4070 SPINMINUTES=SPINMINUTES+3: 'If spincycle is running,
add 3 minutes each pass through subroutine.
4080 IF SPINMINUTES<120 THEN RETURN: 'Spin cycle is still
running. Do not allow any further concentration adjustment.
4090 IF SPINMINUTES>=120 THEN SPINCYLE=FALSE:
SPINMINUTES=0: KILL"injector.var": THISFLAG=0: RETURN:
'Spincycle is done. Resetting THISFLAG prevents the low
average injection test from occurring for at least an hour.
4100 IF COUNTS<4560 THEN LOWRDN=TRUE: 'Count rate falls
below setpoint for low radon decision.
4110 IF LOWRDN=FALSE AND LOWPASS=0 THEN RETURN: 'Radon level
is OK.
4120 LOWPASS=LOWPASS+1: 'Radon is low. Increment lowpass
counter.
4130 IF LOWLEVEL=TRUE THEN 4190: 'This flag sets only on the
second consecutive low count. Program is now committed to
try to take corrective action.
4140 CTS(LOWPASS)=COUNTS: 'Store first 2 counts for
averaging.
4150 IF LOWPASS=1 THEN RETURN: 'Lowrdn flag is set. Wait for
next cycle to see if true low radon condition exists.
4160 IF LOWPASS=2 THEN INITAVG=(CTS(1)+CTS(2))/2: 'Average
first 2 counts.

```

```

4170 IF INITAVG<4560 THEN LOWLEVEL=TRUE ELSE LOWRDN=FALSE:
LOWPASS=0: 'Low radon condition is verified. Now wait for
counts 5-7 to determine number of injections.
4180 RETURN
4190 CTS(LOWPASS)=COUNTS: 'Store the counts for each cycle.
4200 IF LOWPASS<7 THEN RETURN: 'Take no injection action
until cycle 7.
4210 LOWAVG=(CTS(5)+CTS(6)+CTS(7))/3: 'Average counts from
cycles 5-7.
4220 DEFICIT=4800-LOWAVG: 'Calculate average number of
counts below 4800 setpoint.
4230 DEFICIT=DEFICIT*10/7: 'Average is only 70% of the drop
which will be realized. Increase the average deficit by
42.857% to predict the real total drop.
4240 DEFCON=DEFICIT*.02492: 'Calculate the number of pCi/l
which need to be made up.
4250 DEFPCI=DEFCON*833: 'Calculate the total number of pCi
which need to be made up.
4260 DEFINJ=DEFPCI/1395: 'At 1395 pCi per injection,
calculate the number of injections needed to bring
concentration back up.
4270 IF DEFINJ<=10 THEN NBRINJ=DEFINJ: GOSUB 1580: NBRINJ=0:
DEFINJ=0: LOWPASS=0: LOWRDN=FALSE: LOWLEVEL=FALSE:
SPINCYLE=TRUE: RETURN: 'If number of injections <=10, then
do them all. Reset all injector flags. Set spincycle flag:
120 minute dead time.
4280 IF DEFINJ>10 THEN NBRINJ=10: GOSUB 1580: NBRINJ=0:
DEFINJ=DEFINJ-10: RETURN: 'Can't do all injections at once.
Do 10. Wait until next cycle to do more.
4290 NBRINJ=DEFINJ: GOSUB 1580: NBRINJ=0: DEFINJ=0:
LOWPASS=0: LOWRDN=FALSE: LOWLEVEL=FALSE: SPINCYLE=TRUE:
RETURN: 'Perform all remaining injections. Reset all
injector flags. Start 120 minute spincycle (injector dead
time).

4300 'SUBROUTINE:---SAVE INJECTOR VARIABLES---
4310 OPEN "injector.var" FOR OUTPUT AS #3: 'Prepare to save
injector variables in case of power outage.
4320 PRINT #3, DEFINJ, SPINCYLE, SPINMINUTES, LOWRDN,
LOWPASS, LOWLEVEL: 'Save variables to disk.
4330 CLOSE 3

4340 'SUBROUTINE:---LOAD INJECTOR VARIABLES---
4350 ON ERROR GOTO 4390: 'Turn on error trapping.
4360 OPEN "injector.var" FOR INPUT AS #3: 'Open file to load
injector variables.
4370 INPUT #3, DEFINJ, SPINCYLE, SPINMINUTES, LOWRDN,
LOWPASS, LOWLEVEL: 'Load injector variables.
4380 CLOSE3: DATAOK=TRUE: GOTO 4400: 'DATAOK flag=true means
injector variables are valid.

```

```

4390 CLOSE 3: DATAOK=TRUE: RESUME 4400: 'The file did not
exist on powerup. This means the injection process was not
underway when the power was lost. The normal powerup flag
conditions are OK.
4400 ON ERROR GOTO 0: 'Turn off error trapping.
4410 RETURN

4420 'SUBROUTINE:---REPLACE SHOTS---
4430 IF REPSHOTS<=10 THEN NBRREP=REPSHOTS: GOSUB 1750:
REPSHOTS=0: GOTO 4450: 'Since number of replacement shots
<=10, then do them all.
4440 NBRREP=10: GOSUB 1750: REPSHOTS=REPSHOTS-10: 'Number of
replacement shots is more than 10, so only do 10 on this
cycle.
4450 OPEN "log.dat" FOR APPEND AS #3: 'Prepare to update
log.dat file.
4460 PRINT #3,"Replacement shots performed at "; TIME$; " on
"; DATE$; " = "; NBRREP: CLOSE 3: 'Annotate log.dat file.
4470 IF REPSHOTS<0 THEN REPSHOTS=0: 'Can occur by manual
replacement.
4480 ON ERROR GOTO 4520: 'Turn on error trapping.
4490 IF REPSHOTS=0 THEN KILL"repshots.dat": REPFLAG=FALSE:
RETURN: 'When all replacement shots have been made, erase
the REPSHOTS.DAT file from disk.
4500 OPEN "repshots.dat" FOR OUTPUT AS #3: 'All replacement
shots haven't been made so prepare to update REPSHOTS.DAT
file
4510 PRINT #3,REPSHOTS: CLOSE 3: RETURN: 'Update
REPSHOTS.DAT file.
4520 RESUME 4530: 'Perform in case of error.
4530 ON ERROR GOTO 0: RETURN: 'Turn off error trapping.

4540 'SUBROUTINE:---TOGGLE AUTOINJECT OPTION---
4550 IF AUTOINJECT=FALSE THEN AUTOINJECT=TRUE: LOCATE 25,77:
PRINT" ON";: RETURN
4560 IF AUTOINJECT=TRUE THEN AUTOINJECT=FALSE: LOCATE 25,77:
PRINT"OFF";: RETURN

4570 'SUBROUTINE:---TOGGLE PRINT VARIABLES OPTION---
4580 LOCATE 3,1: IF VARS=FALSE THEN VARS=TRUE: PRINT LOWRDN;
LOWLEVEL; LOWPASS; DEFINJ; SPINCYCLE; SPINMINUTES; "      ":
RETURN
4590 IF VARS=TRUE THEN VARS=FALSE: PRINT BL2$: RETURN

```


Appendix D

Radon Control Program Description

General Function

The radon control program (RCP) is basically designed to control the radon chamber and monitor the environmental parameters. The software to accomplish this is fairly simple and straightforward. However, if no other features were added to the program, its usefulness as a research tool would be limited. Therefore, the RCP was designed to be as user-friendly and full-featured as possible within the constraints of GW-BASIC.

The RCP is designed to operate autonomously; no intervention is required on the part of an operator. The utilities that are provided as research aids are interventions to the normal function of the program and can, if used injudiciously, hinder the normal operation of the program. However, when used correctly, the operator will find that the program is simple to use and is very versatile. The utilities and directions on how to correctly use them are discussed in detail later in this appendix.

The program was written in GW-BASIC version 3.22. Because of limitations of the memory available using this language, minimum documentation was included in the actual program.

However, the program listing in Appendix C includes a remark statement at the end of virtually every line of the program, explaining each line's function.

Radon Control Program Automatic Functions

The RCP is designed to perform all control and monitoring functions of the radon chamber automatically. This includes automatic boot-up of the entire system even after a power failure. More information on this can be found in appendix B, Setting Up the PC. The entire radon chamber system can be monitored in real-time on the computer display. A photograph of a typical display is shown in figure 22.

In the normal operating mode, the program cycles through a loop that checks the system clock at regular intervals to determine if any particular routines need to be performed. Figure 23 is a flowchart of the basic RCP functions.

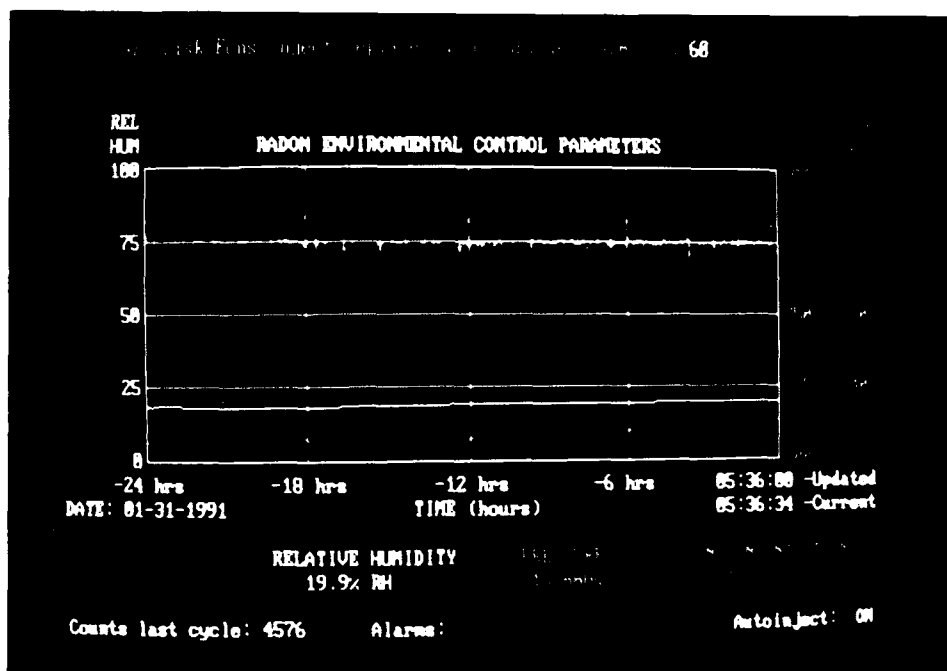


Figure 22. Typical Radon Control Program Display

Every 20 seconds, the system communicates with the Solomat MPM4000 through the COM2 serial port and reads the current temperature, relative humidity, and barometric pressure data and prints these values on the lower part of the computer screen. The temperature data is printed in red, the relative humidity in yellow, and the barometric pressure in blue. The radon concentration, coded in green, is not updated at this point because the counter is only read at each 3-minute interval. The temperature, relative humidity, and barometric pressure

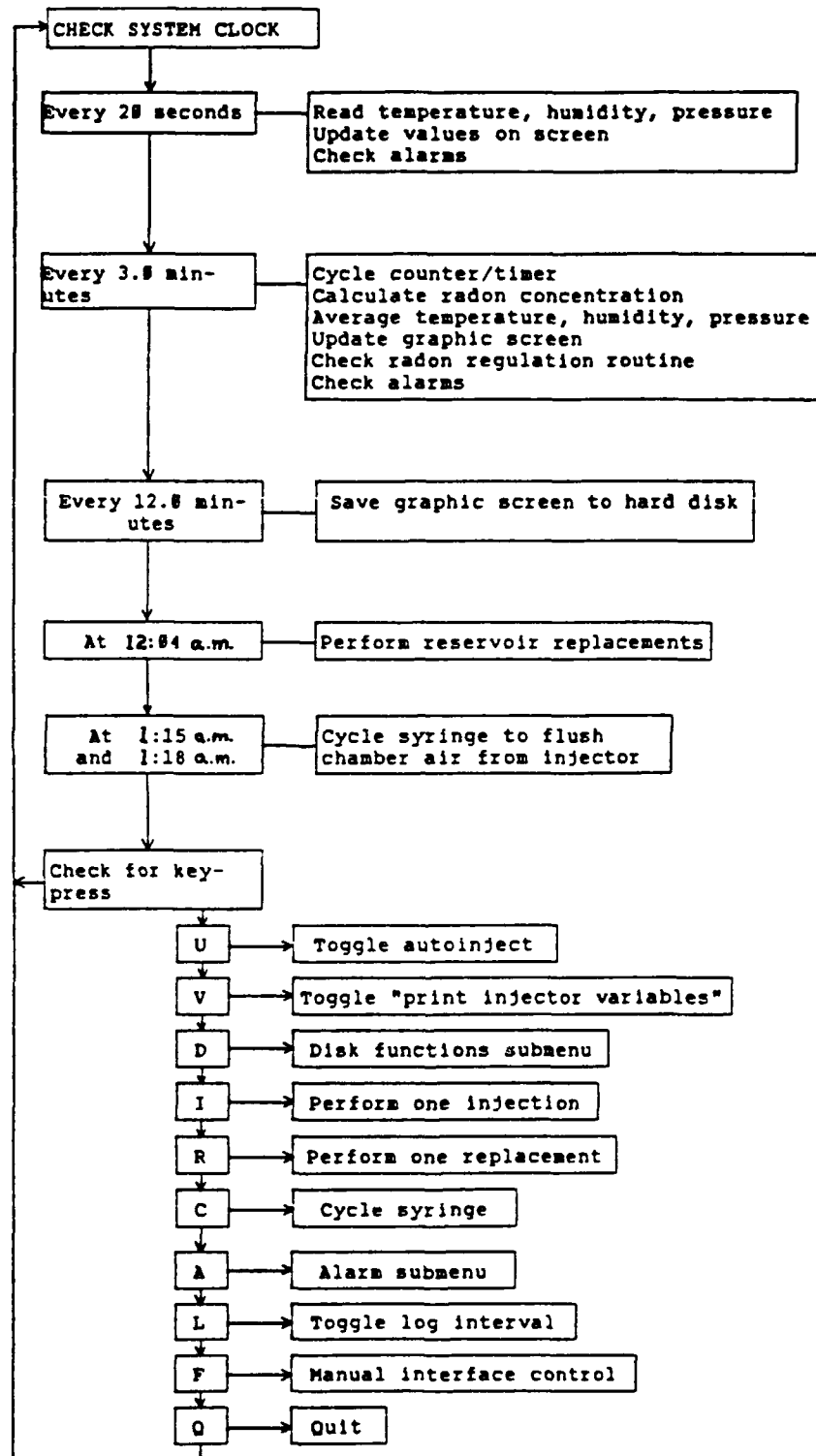


Figure 23. Radon Control Program Flowchart

data are accumulated each time they are collected for averaging at the end of each 3-minute cycle when they will be plotted in the graphic area.

The temperature, relative humidity, and barometric pressure data are also checked every 20 seconds to determine if any of the parameters have exceeded their alarm limits. If any limits are exceeded, an alarm is turned on at the bottom of the screen. This will be discussed in more detail later.

When the system clock reaches an even 3-minutes, such as 12:00, 12:03, 12:06, etc., a number of functions are performed by the RCP. First, the Ortec 996 counter/timer is cycled, meaning that the timer is stopped, the number of counts is read, the counter is reset, and the counter restarted. Once the number of counts is determined, the radon concentration can be calculated. Since this is the end of a 3-minute cycle, the temperature, relative humidity, and barometric pressure are averaged over the last three minutes. Now the program has average data for the last three minutes for all four monitored parameters.

The program now updates the graphic screen in the center of the display. The data plotted on the far right side of the screen reflect current data. The time that the most current data was last plotted is printed at the bottom right corner

of the plot above the current time clock. When the program updates the graph, any data which already existed on the screen is shifted to the left by one pixel. Then the new data are plotted at the extreme right side of the graph, and a line is drawn from the previous data points to the new ones. There are 480 pixels across the plotting area. Because each pixel represents three minutes of data, the entire plot represents 1440 minutes or 24 hours of data. Once any data reaches the left side of the plot, it becomes older than 24 hours at the end of the next 3-minute cycle and is discarded. By this method, the plot is constantly updated every three minutes and shows the data for temperature, relative humidity, barometric pressure, and radon concentration for the last 24 hours.

The ranges of the monitored parameters are programmed to be displayed between different limits, and each parameter has its own scale. The temperature is shown on the left side of the screen in red, ranging from 0 to 40 degrees centigrade. The relative humidity scale, also on the left but in yellow, ranges from 0 to 100 percent. On the right-hand side of the plot, the barometric pressure scale in blue ranges from 700 to 800 millimeters of mercury, and the radon scale in green ranges from 0 to 160 pCi/liter.

Once the screen has been updated to reflect all the current data, the program diverts to the subroutine that checks the radon concentration and takes whatever action is required. Chapter 4 discusses the logic within this subroutine in detail.

The next function performed on the 3-minute cycle is the checking of all four parameters to see if they are within their respective operating limits as selected by the operator, or whether an alarm should be turned on. This is the only time that the radon concentration is checked, because the concentration is only calculated at the end of each 3-minute cycle.

To minimize data loss in case of a power failure, the graphic screen data is saved to the hard disk every 12 minutes. This also allows the operator to stop the program at any time without losing the entire plot. When the program is restarted, the program loads the graphic data back into memory. However, the program must perform an extra manipulation with the data before it is displayed. Because the data on the graph is time-coded, the program checks to see how old the newest data in the data file is. It then shifts the data to the left the appropriate number of pixels so that when the data is redisplayed, it will be placed correctly on the graph with

respect to the time that the program is restarting. If the data in the data file is more than 24 hours old, then none of the data will be redisplayed.

Another automatic function on a timed cycle is the replenishing of air into the radon reservoir which might be needed because of injections removed from the reservoir during the last 24 hours. When injections are made during the day, a volume of radon is transferred from the radon reservoir to the chamber, but it is not replaced immediately. This prevents any dilution of the radon in the reservoir during the course of any experiments. But the volume that is removed from the reservoir must be replaced. The time selected to perform this operation is 12:04 a.m. every day. This should occur well after any experiments that would be done during the day and early enough in the morning that the very small disruption in the reservoir radon will have had time to stabilize before any experiments later in the morning. If any replacements are made, the number of replacements is annotated on the hard disk to a permanent log file called LOG.DAT.

The last automatic timed function is actually part of the radon replacement procedure. At 1:15 a.m. and 1:18 a.m., the RCP cycles the syringe 10 times. This serves to flush the chamber air from the injector in preparation for future injections.

The RCP is designed to be totally rebootable by saving all the necessary variables and data whenever appropriate. The files are set up on the hard disk in the RADON subdirectory by the RCP itself. Once set up, the RCP will also update the files as needed. The files which the RCP maintains are listed in table 7.

FILENAME	INFORMATION STORED
GRAPH.DAT	Screen graphic array.
INJECTOR.DAT	Injector variables: DEFINJ, SPINCYCLE, SPINMINUTES, LOWRDN, LOWPASS, LOWLEVEL.
LIMITS.DAT	Alarm limits for all parameters.
LOG.DAT	Logging of all important operations performed and data.
REPSHOTS.DAT	Number of replacement shots to perform at 12:04 a.m.

Table 7. Files Maintained by Radon Control Program

Radon Control Program Optional Features

The RCP uses a page-flipping technique to reduce the screen-update time each three minutes. This technique requires the use of a one-dimensional array containing 21255 elements. Even though the elements are defined as integers, each element requires two bytes of memory. As a result, the remaining amount of memory available for the actual program is greatly reduced. Although the RCP is designed to be as fool-proof and user-friendly as possible, memory constraints limited the

amount of programming that was done along these lines. Consequently, it is important here to explain the precautions that the operator should take any time that the program is required to do anything other than its normal, automatic functions.

PRECAUTIONS:

Each time the RCP cycles through its main loop, it checks to see if any keys have been depressed to select any optional features, and the timing of the main loop has just been described. The performance of those regularly scheduled tasks occurs only when the program is able to check the system clock and make a determination if any action should be taken at a particular time. Any time that an optional feature is used, the RCP branches away from its main loop to perform the desired function. It is very important, therefore, to perform auxiliary operations only when it will not interfere with the normal operation of the program. Some of the optional features will only change the state of a flag, but most will either perform a task that will take a nontrivial amount of time or drop into a submenu from which the operator must leave to return the program to its normal function.

The RCP was designed to allow the operator as much latitude as possible when using the program, and certain timed operations

may be overridden harmlessly. First of all, the environmental parameters are read from the Solomat MPM4000 every 20 seconds, updated on the screen, and added to an accumulation register for averaging at the end of the 3-minute cycle. During the same procedure, the alarms for those parameters are checked. If the operator causes the program to branch to an option and this cycle is missed, no loss or corruption of data occurs. When the environmental parameters are averaged, the accumulation registers are divided by a counter that is only incremented whenever a new set of Solomat data is read. This data is read at the 3-minute cycle as well. This means that as long as the 3-minute cycle is successfully accomplished, the environmental parameter information on the screen will be correct. The only change that occurs if an option being executed interferes with these particular automatic functions is that the number of readings that are averaged during the 3-minute period will be less.

Immediately after the environmental parameters are read, each is checked to determine if it is within operator-selected limits or if an alarm should be triggered. If the operator is executing an option that precludes this operation, the alarms simply will not be checked until after the program is return to its normal function.

The only program intervention problem that the operator will have is when the program is not in its normal operation mode when a 3-minute cycle is due to be executed. The reason for this is quite simple. During the 3-minute-cycle operations, the Ortec 996 counter/timer is stopped, reset, and restarted, and the data for that 3-minute period provides the radon concentration. The on-screen graph is also updated with all four parameters. If the program misses just one 3-minute cycle, the counter/timer will not be cycled, and at the next 3-minute cycle, the count for the radon concentration will be twice as high as normal because the counter was not reset. Not only will a large spike occur on the radon line on the graph, but the timing of the graph data will be off by three minutes as well.

Because the program has many automatic functions to perform, when the operator presses a key to engage an optional feature, the computer may not immediately switch to the selected function. However, as soon as the program completes whatever task it is currently performing, it will branch to the optional feature.

The two main guidelines that the operator should constantly be aware of are:

1. Always return the RCP to its normal function mode in time to perform its 3-minute cycle.

2. Do not press an option-select key more than once. The program will branch to the option as soon as it can.

Each optional feature of the RCP will now be explained, and the approximate time to accomplish each, when applicable, will be mentioned.

Toggle Autoinject

The RCP is designed to control the radon concentration in the radon chamber automatically. However, during the course of research, it may be that this function needs to be turned off. The autoinjection software switch is toggled by pressing either "u" or "U". The condition of the switch is continuously shown in the lower right-hand corner of the computer screen. Because of the need for automatic reboot, the autoinject switch is turned on during system initialization.

When the autoinjection switch is turned off, no action may be taken by the radon regulation subroutine to adjust the radon concentration in the chamber. However, if the RCP has performed an automatic injection within the last two hours, a flag called SPINCYCLE will be set to prevent further automatic concentration adjustment until the two hours has expired. The variable SPINMINUTES keeps track of this time and will continue to be incremented when the autoinject switch is off. When SPINMINUTES

reaches 120 minutes, it will be reset to zero, and the SPINCYLE flag will be cleared.

If the autoinject switch is turned off after the program was committed to attempting regulation (LOWLEVEL flag is set) but before any injections have actually occurred, then further action by the regulation subroutine is stopped. However, when the switch is turned back on, the subroutine will continue where it left off.

If the autoinject switch is off, manual radon injection is not hindered in any way. Only the automatic injection feature is disabled. Manual injection is discussed later.

Toggling this option cannot interfere with the normal function of the RCP at the 3-minute cycle.

Toggle "Print Injector Variables"

There are six main variables that indicate the condition of the radon regulation routine: LOWRDN, LOWLEVEL, LOWPASS, DEFINJ, SPINCYLE, and SPINMINUTES. These variables, discussed in detail in chapter 4, are not normally printed to the computer screen unless that option is selected. Once selected, the variables are printed just below the main option line on the left-hand side of the display and will continue to be updated on the screen until the option is turned off. Figure 24 shows

a typical screen with the injector variables displayed, where all the variables are "0". The option is toggled by typing either a "v" or a "V". The variables will be printed to the left of the screen, just below the option line at the top of the display. Table 8 lists the variables in the order in which they are printed to the screen and summarizes what each variable represents.

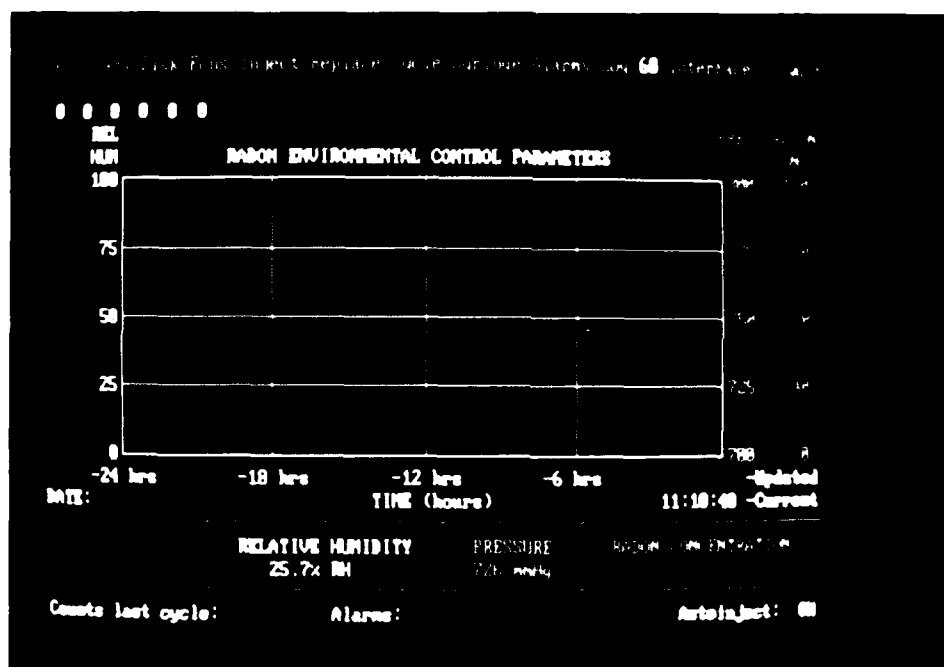


Figure 24. Computer Display Showing Injector Variables

	VARIABLE NAME	FUNCTION OR DESCRIPTION
1	LOWRDN	Flag that is set when first low radon concentration level is detected.
2	LOWLEVEL	Flag that is set when the second low radon count is detected. Setting this flag commits the RCP to attempting to adjust the concentration unless the autoinject switch is turned off.
3	LOWPASS	Number of passes through the radon regulation routine when a low condition has been detected. Corresponds to T1, T2, etc.
4	DEFINJ	Number of injections that the RCP has determined need to be performed which have not yet been performed.
5	SPINCYCLE	Flag which, when set, prevents further automatic radon regulation for 120 minutes.
6	SPINMINUTES	Number of minutes remaining that automatic injection has been forbidden to allow equilibration of counting system.

Table 8. Autoinjector Variables

Selecting or deselecting this option cannot interfere with the normal operation of the RCP when the 3-minute cycle is due.

Disk Functions Submenu

There are three disk functions that can be accessed while the RCP is running. They are accessed by a pull-down menu which is printed just below the main option line at the top of the screen when a "d" or "D" is pressed. The three options available are to print the log file, transfer the log file to

floppy disk, and reset the log file. Refer to Figure 25 for an example of the computer screen showing the disk functions submenu. **CAUTION:** Selection of this submenu should not be attempted unless there is plenty of time to accomplish the desired task and return to the main program before the 3-minute cycle is due. The best time to perform disk functions is immediately after a new 3-minute cycle has begun. Whichever option is selected, immediately upon completion, the program will return to its normal cycle.

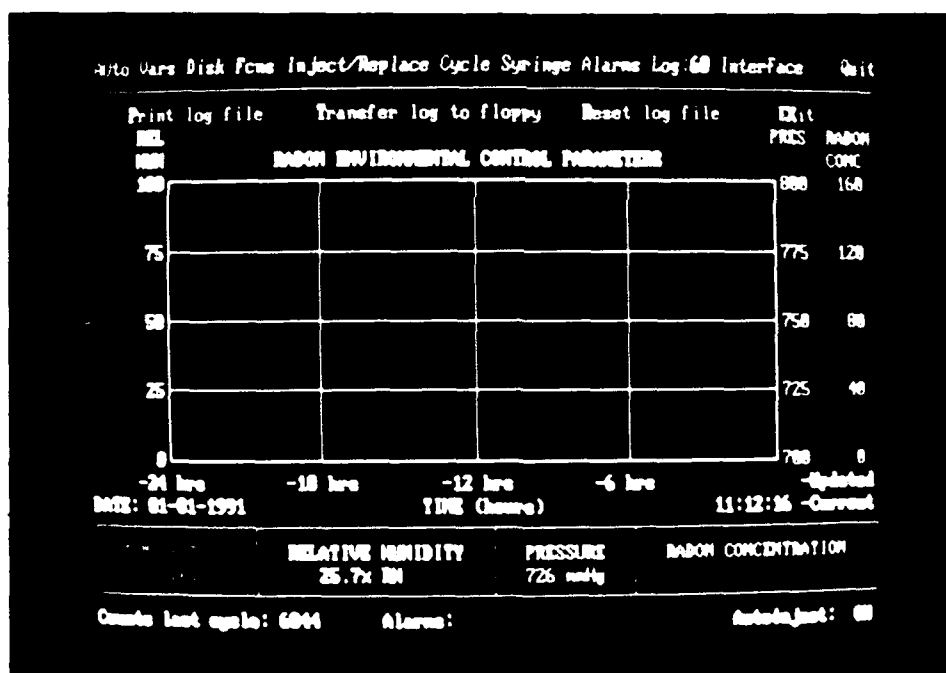


Figure 25. Disk Functions Submenu

The RCP makes a permanent record of the radon and environmental parameters at an interval selected by the operator

(discussed later), and also of each time the program is restarted, injections or replacements are performed, or the LOG.DAT file is erased. To send this file to the line printer without disrupting the program, the first option can be selected, "Print Log File", by pressing a "p" or "P". The entire LOG.DAT file will be printed. Ensure that the printer is ready before selecting this option or an error will terminate the program.

The next option is "Transfer log to floppy". This option is selected by pressing either the "t" or the "T". This function will copy the entire LOG.DAT file from the hard disk to the floppy drive. Ensure that a formatted floppy disk is ready to receive the data, or an error will occur, terminating the program. After selecting this option, a prompt asks for a filename to give the new file, such as "1Jan.log". Do not enter a drive designation with the filename. Drive "a" is already programmed as the destination drive. Again, make sure that there is enough time to perform this function before the RCP's 3-minute cycle is due.

The third option is "Reset log file" and is selected by pressing "r" or "R". Once a file has been transferred to a floppy disk, it may not be necessary to keep the data on the hard disk anymore. This option will erase the entire LOG.DAT

file and then reopen a new LOG.DAT file, making a first entry noting that the file was reinitialized, along with the time and date. This option only requires about 5 seconds to complete.

The last option is "Exit", accessed by typing "x" or "X". This will return the program to normal operation without performing any disk functions.

Perform One Injection

This option, selected by typing "i" or "I" at the main menu, will perform one radon injection into the radon chamber. Prior to doing the actual injection, the syringe will be cycled once to prime the solenoid valve (discussed below). Performing one injection will take about 20 seconds before the program returns to its normal function, so ensure there is adequate time for the operation to finish before the RCP's 3-minute cycle comes due. After the injection occurs, the LOG.DAT file will be annotated that an injection was performed, also noting the date and time. The number of replacement shots that will need to be performed at the end of the day will also be incremented by one.

Perform One Replacement

To perform one radon replacement, select this function by typing "r" or "R". The injector will draw one volume of air

from the radon chamber and express it into the radon reservoir. The LOG.DAT file will be annotated accordingly, along with the date and time, and the number of replacement shots that need to be performed at the end of the day will be decremented by one. This function requires about 20 seconds to perform, so it should not be executed too close to a 3-minute cycle.

Cycle Syringe

This function does not perform an injection or make a replacement. It opens solenoid valve 1 of the radon injector to the radon reservoir and then draws and pushes the syringe to charge the plenum of the solenoid valve with fresh radon from the reservoir. After the syringe is fully pushed, the solenoid valve is closed. This function takes about 6 seconds to perform and is selected by pressing either "c" or "C".

Alarm Submenu

The RCP allows the option of setting alarms for each monitored parameter by using the alarm submenu. Once the lower and upper limits are set, each time the program gets a new value for each parameter, it checks to see if the parameter is within the set limits. If a parameter falls outside these limits, then an alarm is turned on at the bottom of the screen in the area designated for alarms. Unless a parameter is of particular interest, logical settings for each parameter would

be at the minimum and maximum display values, such as a lower limit of 700 and a maximum of 800 millimeters of mercury for barometric pressure.

Whenever an alarm limit is changed, the alarm limits are automatically saved to the hard disk to a file called LIMITS.DAT, and any time the system reboots, the limits are loaded back into the program from the disk. Once the submenu is accessed by typing "a" or "A", the parameter of interest must be selected. Figure 26 shows an example screen with the alarm submenu directly under the main menu line.

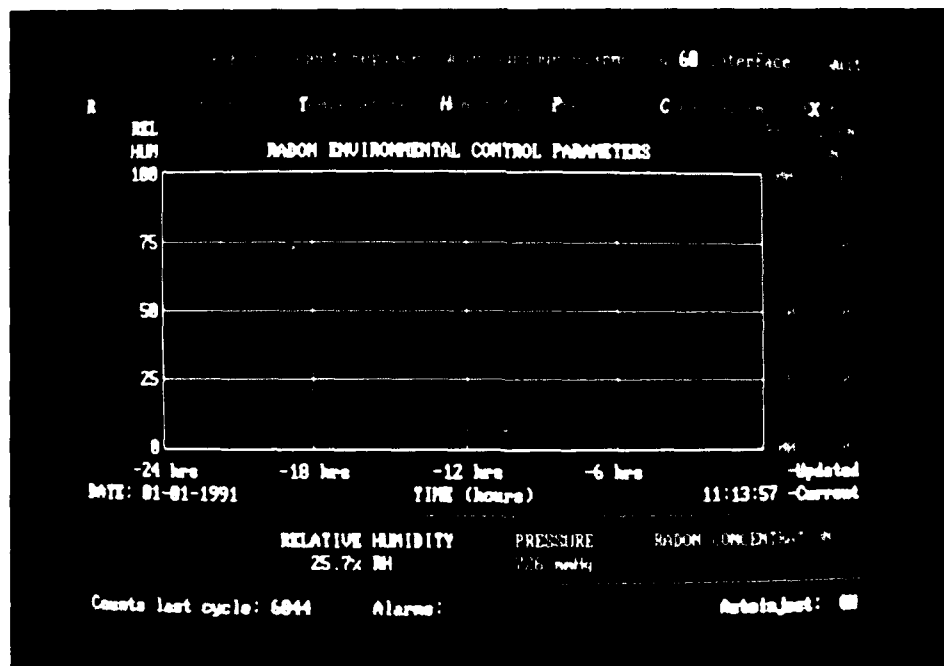


Figure 26. Alarm Submenu

From the alarm submenu, either type the first letter of the parameter to look at its limits, type a "c" or "C" to clear any existing alarms, or type "x" or "X" to exit back to the main program.

Once a parameter is selected from the alarm submenu, another submenu appears and offers the option of either looking at the limits for that parameter or changing them. The option is selected by pressing either "L" to look at the parameters or "C" to change the settings. Figure 27 is a photograph of the screen showing this submenu.

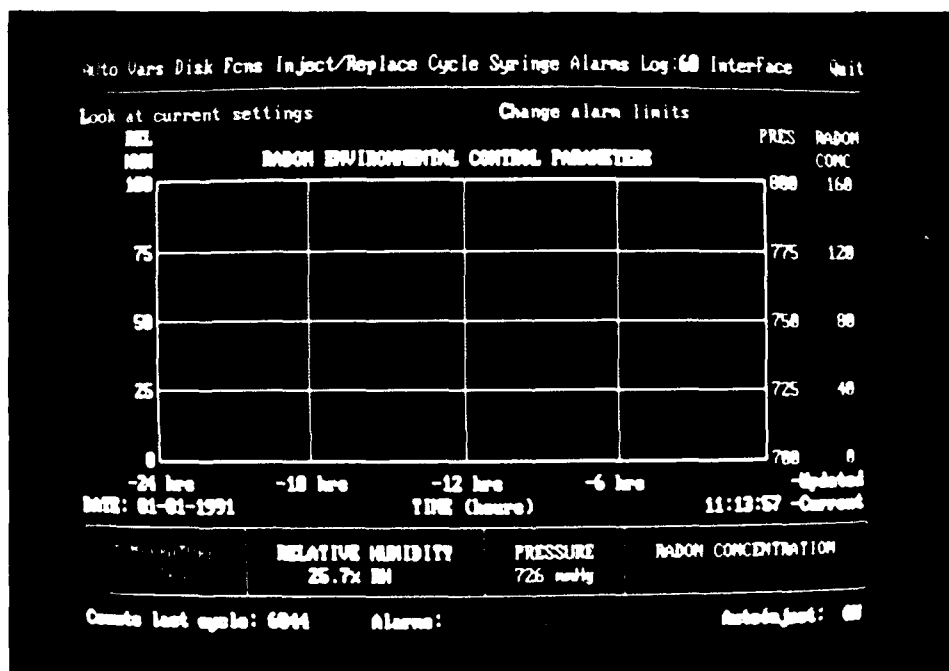


Figure 27. Alarm Parameter Submenu

If the option to look at the settings is chosen, the lower and upper limits for the parameter of interest are shown. Figure 28 shows an example of the limit settings for radon.

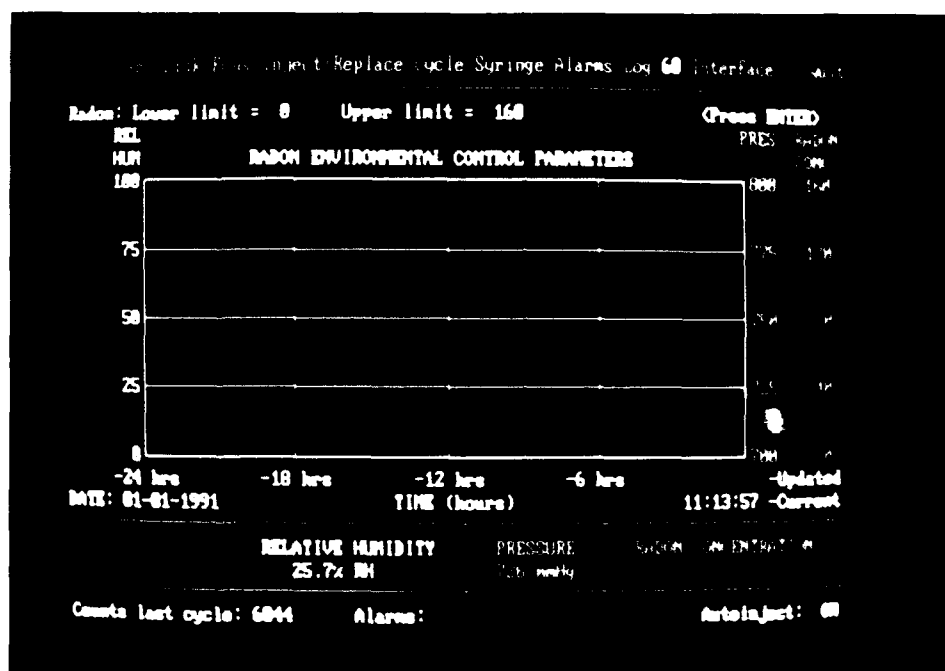


Figure 28. Radon Limits Display

If it is desired to change the limits, the program provides a prompt for the lower limit first and then the upper limit. After each of these functions, the program returns to the alarm submenu.

When an alarm is triggered, an abbreviation for the parameter which caused the alarm is printed in its color-code at the bottom of the screen. Figure 29 shows an example screen where all of the possible alarms have been triggered.

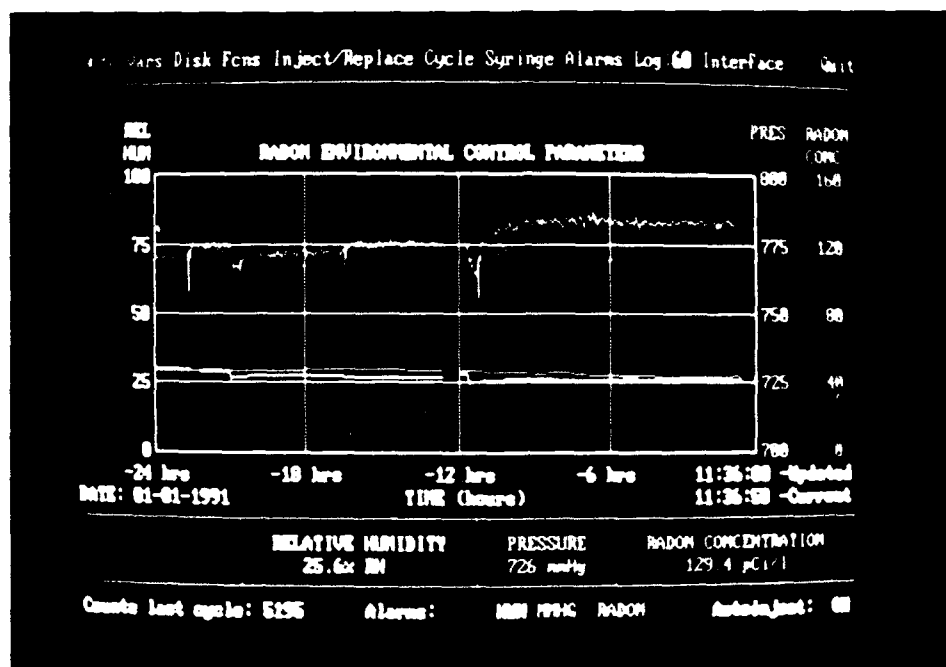


Figure 29. Computer Display Showing All Alarms

Once alarms have been triggered, they can be cleared from the bottom of the screen by using the "Clear" function on the alarm submenu. This will erase any alarms that are printed in the alarm area at the bottom of the screen. However, if an alarm condition still exists, then the alarm will be reset as soon as the parameter that lies outside the set limits is reevaluated by the computer.

The RCP is not in its normal operating mode as long as the submenu is still active, and the submenu should be exited before the RCP's 3-minute cycle is due.

Toggle Log Interval

One of the automatic functions of the RCP is to log the data for the radon concentration, temperature, relative humidity, and the barometric pressure for a permanent record. Normally the interval at which this data is saved is 60 minutes, and that interval is selected automatically by the program when it is initializing. However, if a more detailed record of the data is needed, the log interval can be toggled to three minutes by pressing the "1" or "L". The particular logging interval that is selected is also printed on the menu line beside the log option. If the log interval is set to three minutes, the normal data that would have been logged at 60 minutes will still be printed at the appropriate time, but it will be supplemented by the data which is also collected at each 3-minute cycle. The temperature, relative humidity, and barometric pressure never reflect more than an average over the three minutes prior to its being logged. However, the data that is written on the radon concentration at 60-minute intervals reports the average radon concentration for the

preceding hour. The counts reported for the hour is the sum of the 20 3-minute-interval counts that occurred during the preceding 60 minutes.

The data which is written to the LOG.DAT file is listed in table 9, along with the column in which it is written, and the units of the data, if appropriate.

COLUMN	DATA	UNITS
1	Date	not applicable
2	Time and interval	not applicable
3	Counts	none
4	Radon concentration	pCi/liter
5	Temperature	Degrees centigrade
6	Relative humidity	percent
7	Barometric Pressure	millimeters of mercury

Table 9. Data Logging Format

Care should be exercised if the RCP is left unattended for long periods of time. If the logging interval of 60 minutes is selected, then the LOG.DAT file will not get large very fast. But if the data is logged every three minutes, then a very large file could be written to the hard disk in a very short time.

Toggling this function will not interfere with the normal operation of the RCP at any time.

Manual Interface Control

This function is accessed by typing either "f" or "F". This option allows the operator to send a code directly to the interface which will then energize whatever relays are addressed by the particular code sent. This could be useful if the operator were experimenting with a different injection sequence perhaps. After this option is selected, a prompt will appear under the main menu line asking for the code to send to the interface. To return to the main program, press the enter key without entering a number. A complete discussion of how interface codes can be selected can be found in chapter 2.

As long as this function is active, the RCP cannot access the clock, so control must be returned to the program in time for the 3-minute cycle.

Quit

If a complete exit from the RCP is desired, type either a "q" or "Q", and the program will terminate, returning to its normal screen mode. This will not alter or destroy any of the data files on the hard disk; it simply terminates the program normally.

Screen Capture

Another function that can be very useful is a utility to save the screen image on the computer. However, this option is not a function of the RCP, but it is a utility called SCR.EXE that is included with the word processor, Lotus Manuscript. If capturing the computer screen for use later is important, then the purchase of this program or one similar should be considered. The SCR.EXE program is memory-resident and can be installed into memory automatically by loading the program with the AUTOEXEC.BAT file in the computer's root directory.

The SCR.EXE utility can save the entire screen or any part thereof to a file on either the computer's hard disk or on a floppy disk. The file can then be imported into a Lotus Manuscript document and viewed or printed out. Figure 30 was generated using the SCR.EXE utility.

To capture a screen using SCR.EXE, press SHIFT and PrtSC simultaneously. Once the program is called, it will provide its own explanatory prompts.

This utility should only be invoked when the RCP is not performing any automatic functions, or communication problems may occur. The SCR.EXE utility can take about a minute to execute, so ensure there is plenty of time to complete the screen capture before the RCP's 3-minute cycle is due.

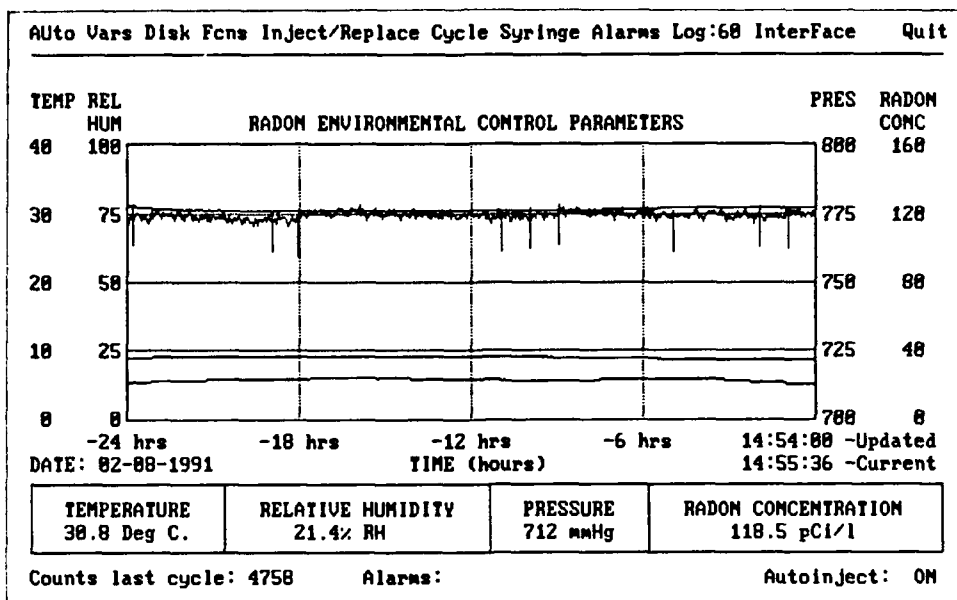


Figure 30. Screen Capture Example

Appendix E

Solomat MPM4000 Programming

In the event that the Solomat MPM4000 loses its program or if the program should become corrupt, it is necessary to use the CS4 software provided by Solomat Instrumentation to reprogram the Solomat system. The following instructions will guide the user through the necessary steps to reprogram the MPM4000. These steps do not necessarily indicate all the changes that must be made using the CS4 software, but do show the correct settings for all the parameters needed to correctly program the MPM4000.

1. Reset the MPM4000 by turning it off, then turn it back on while depressing the hold/shift, the Enter/Yes, and the down-arrow buttons simultaneously.
2. Now using the PC, change directory to the one containing the CS4 software (SOLOMAT directory).
3. Select CONFIGURE from the main menu.
4. Select MPM and the MPM4000.
5. Change the settings as necessary to be as shown; press ENTER to accept correct options.

MPM Type: MPM4000
Port: 2
Baud Rate: 4800
Word Length: 8
Stop Bits: 1
Parity: None

6. Use escape to return to main menu, then enter the PROGRAM menu by selecting PROGRAM with the cursor and then pressing ENTER twice. If the program fails to communicate with the MPM4000, select ABORT OPERATION at the prompt. <ESCape> to the MAIN MENU and go through the configure process again; then repeat this step.

7. Select PROCEDURES, then LOAD FROM FILE.

8. Using the cursor, select the file, RADON.PRO. This will load the necessary parameters to program the MPM4000. If this file does not exist, refer to the following section in this appendix, Setting Up a RADON.PRO File.

9. Use <ESC> to return to the PROGRAM menu, then select COMMUNICATE.

10. Select SEND 4000 SETTINGS and press ENTER. The MPM4000 will be programmed as required to support the radon workstation system. Any warning messages may be ignored since they refer to functions that are not programmed in this application.

11. Use <ESC> to leave the Solomat CS4 software.

Several functions must be programmed manually into the MPM4000. When programming the MPM4000 directly, pause after instrument correctly registers each keypress.

12. With the MPM4000 on, press the down-arrow key once. The display will read FUNCS.

13. Press Enter/Yes.

14. Press the down-arrow twice. Display will read OPTION.

15. Press Enter/Yes.

16. Press the down-arrow 10 times. The display will read DISPLAY READING TO RS-232 NO.

17. Press Enter/Yes.

18. Press the up-arrow twice. The display will read FUNCS again.

19. Press the down-arrow key 3 times until the display reads OUTPUT.

20. Press Enter/Yes twice. The display will read SEND FILES TO PC.

21. Press Next/No twice. Display will say SEND FILES TO PRINTR.

22. Press Enter/Yes.

23. Press the up-arrow key three times. The sensor data should be displayed. Programming is now complete.

Setting up a RADON.PRO file

Whether the RADON.PRO file is corrupt or missing, the following procedures will set the file up correctly.

1. After running the CS4 software and going into the PROGRAM menu, select CHANNEL SETUP and make any necessary changes to the settings as shown below. In this instance, use the SPACEBAR to change the parameter; press ENTER to accept the one shown.

Module: MPM4013
Range: Pt100
Sensor: Pt100
Symbol: °C
Socket: 1
Multichannel: YES
Alarm: Off

Channel: 1 Selected: YES

MX Channel: 0
Dwell Time: 00:00:00

High: 0.0 Low: 0.0
Custom Calibration
Zero Value: N/A Full Scale: N/A
Dec. Places: N/A

2. When all settings are correct, press F2 to send the commands to the MPM4000.

3. Change the channel number setting to 2 and make any necessary changes as follows:

Module: MPM4013	Channel: 2	Selected: YES
Range: %RH / Dewpoint		
Sensor: 355/6/7 RH		
Symbol: %RH		
Socket: 1	MX Channel: 0	
Multichannel: YES	Dwell Time: 00:00:00	
Alarm: Off		
High: 0.0	Low: 0.0	
Custom Calibration		
Zero Value: N/A	Full Scale: N/A	
Dec. Places: N/A		

4. When all settings are correct, press F2 to send the commands to the MPM4000.

5. Change the channel number setting to 3 and make any necessary changes as follows:

Module: MPM4013	Channel: 3	Selected: YES
Range: Pressure/Pitot		
Sensor: Barometric - 515 BP		
Symbol: mm Hg		
Socket: 2	MX Channel: 0	
Multichannel: YES	Dwell Time: 00:00:00	
Alarm: Off		
High: 0.0	Low: 0.0	
Custom Calibration		
Zero Value: N/A	Full Scale: N/A	
Dec. Places: N/A		

6. Again, when all parameters are correct, press F2 to send the commands to the MPM4000.

7. Press <ESC> to exit to PROGRAM menu.
8. From the Program Menu, select OUTPUT, and then PRINTER.
9. Ensure that the printer parameters are set up as shown below:

Baud Rate: 9600
Word Length: 8
Stop Bits: 1
Parity: NONE
Add Linefeed: NO
Page Width: 40
Char Delay: YES

10. Press F2 to send the commands to the MPM4000.
11. Press <ESC> twice to return to PROGRAM menu.
12. Select FUNCTIONS, then OPTIONS.
13. Ensure that the parameters are selected as follows:

Multichannel: YES	Dwell Time: 00:00:00
Reset MPM: NO	
Custom Menu: NO	Password: MPM4K0
RS232 Port: OFF	
Log Action: NONE	Fast Update: NO

14. Press F2 to send the commands to the MPM4000.
15. Use <ESC> to return to the PROGRAM menu.
16. Select COMMUNICATE, then READ 4000 SETTINGS. The parameters that were just programmed into the MPM4000 will be read back into the program.
17. After the settings have been read back in, use <ESC> to return to the PROGRAM menu.

18. Select PROCEDURES.

19. Select SAVE TO FILE, and enter the filename RADON.

20. The RADON.PRO file is now set up and in so doing, the MPM4000 has been simultaneously programmed. Press <ESC> until the CS4 software terminates.

21. Now refer back to step 12 in the first section of this appendix to complete the MPM4000 programming.

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Vita

Captain William R. Wharton, Jr. was born on July 7, 1954 in Montgomery, Alabama. He graduated from Long Beach High School in Long Beach, Mississippi in 1972. In 1977, he enlisted in the Air Force and after graduating from technical school with honors, he taught electronics at Keesler Air Force Base, Mississippi for five years. He attended Mississippi State University where he received his Bachelor of Science degree in nuclear engineering in 1986. He received a commission in the Air Force in 1986 and performed the duties of nuclear research officer at Headquarters Foreign Technology Division at Wright-Patterson Air Force Base, Ohio until 1989. He anticipates receiving his Master of Science degree in nuclear engineering from the Air Force Institute of Technology in March 1991. He is married to Charlotte Fordyce Wharton and has a daughter, Cynthia Marie.

REPORT DOCUMENTATION PAGE		FORM 100-1 MAY 1962 EDITION GPO WASHINGTON, D.C.	
1. DATE OF REPORT March 1991		2. REPORT TYPE AND DATES COVERED Master's Thesis	
4. TITLE AND SUBTITLE AN ENVIRONMENTALLY CONTROLLED CHAMBER FOR THE STUDY OF RADON DETECTION		3. FUNDING NUMBERS	
6. AUTHOR(S) William R. Wharton, Jr., Captain, USAF			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Institute of Technology, WPAF, OH 45433-6583		8. PERFORMING ORGANIZATION REPORT NUMBER AFIT/EN/GNE/91M-11	
9. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSORING MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES			
12. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited		13. DISTRIBUTION CODE	
14. ABSTRACT A system was developed to dynamically control and monitor the environment and radon concentration within a glovebox for the study of radon. The system is designed around a personal computer workstation which automates the entire system. The radon concentration is determined using a Lucas cell and a scintillation counting system. This information is used as a base for controlling a radon injection system. When the concentration in the glovebox drops, a precisely-measured volume of high-activity radon is injected into the glovebox, returning the concentration to the normal level. The chamber temperature is controlled by a temperature-controlled bath, which circulates its fluid through a radiator within the chamber. Relative humidity and barometric pressure within the chamber are monitored continuously and recorded by the computer with the radon concentration and temperature data. The system also has features which allow the operator to manually control the operation of the radon injection system. The system was successfully fabricated, integrated, and tested. It maintains the radon concentration at approximately 120 picocuries per liter. The temperature control system does not maintain a constant temperature within the chamber, due mainly to inadequate capacity on the part of the heating/cooling unit which was used.			
14. SUBJECT TERMS Radon, Chamber, Computer, Regulate, Control, Injector, Interface		15. NUMBER OF PAGES 147	
		16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL